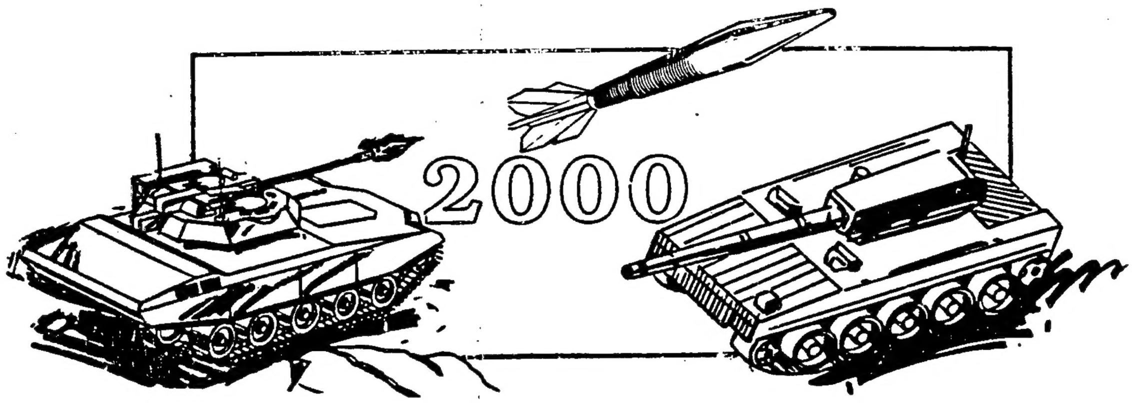
FINAL REPORT

Kinetic Energy Penetrator Long Term Strategy Study

(Abridged)



Prepared for

The Steering Panel
Mr. Michael F. Fisette, Chairman
Assistant Deputy For International Cooperative Programs, AMC

by

The AMCCOM Task Group
Mr. Michael E. Danesi
Task Group Leader

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Abridged for Non-Government Distribution

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EXECUTIVE SUMMARY

To address the perceived increasing burdens associated with use of depleted uranium (DU) as a kinetic energy (KE) penetrator material, the AMCCOM Task Group examined use of alternate materials, and considered the impacts of this in four broad areas: performance; the industrial base; environmental and health factors; and life cycle costs. Application of DU and tungsten alloy (WA) materials to the penetrators for three future weapon systems which will be fielded in the 1995 - 2000 timeframe was considered. These systems are: the Advanced Tank Cannon System (ATAC); Combat Vehicle Armament Technology (COMVAT) Program; and the Kinetic Energy Missile (KEM). The overall objective was to provide data and recommendations which could be utilized by the Government in developing a long term strategy for KE penetrator material selection, and which could also be utilized in addressing related near term problems. This report provides the unclassified and non-proprietary findings of the study, and is intended for distribution to Department of Defense (DOD) contractors with interests in KE penetrator design and manufacture.

Performance

The Ballistic Research Laboratory (BRL) conducted a performance analysis which estimated the capabilities of DU and WA penetrators against the appropriate future threat for each weapon system. The analysis used credible, full scale test data for standard DU and for the best WA currently available against both rolled homogeneous armor (RHA) and non-RHA targets. The results demonstrated, for both RHA and range targets, that DU outperforms WA by a substantial margin. However, this performance gap may be overcome to some extent by using higher technology projectile designs or launch mechanisms for WA than those assumed for the large caliber gun system in this analysis.

An assessment of the emerging technologies which might be available for fielding in the 1995 - 2000 timeframe did not, however, disclose either launch or WA material advancements which would enhance performance significantly and early enough to make WA a low- to medium-risk alternative penetrator material for the ATAC system. A recommendation was made to pursue a long term

effort to enhance WA terminal ballistic performance and to optimize sabot/penetrator designs for WA. This effort should incorporate the recommendations of the ARDEC/BRL/MTL Tungsten Coordination Committee, which are summarized in Chapter II of this report.

There are existing Army and DARPA programs aimed at improving WA penetrator performance. The Army should continue to support these programs, since they may eventually permit the use of WA as a viable alternative to DU for large caliber cannon systems.

For the Navy's 20mm Phalanx system, WA significantly outperforms the DU alloy used in comparison testing. However, the targets used to represent the Phalanx system threat bear no resemblence to the threat targets of interest for Army KE systems.

The Industrial Base

For peacetime production of the penetrators considered in this study, no industrial base capacity problems were identified. Material availability is currently adequate for both depleted uranium and tungsten. The U.S. is dependent on imports of tungsten concentrate, with only one mine currently open in North America. Approximately 50% of U.S. tungsten imports come from mainland China. Barring any cutoff of this supply, availability of tungsten should not be a problem. Any short term supply problems could be met by releases from the stockpile.

The national stockpile of tungsten concentrate is planned for critical applications other than penetrators. In a mobilization situation, imports would most likely be restricted. Thus, a recommendation was made to increase the tungsten concentrate stockpile.

Private sector capacity to process raw material into metallic form for either depleted uranium or tungsten penetrator use is adequate for peacetime. However, under mobilization conditions, shortfalls would exist for both materials. Equipment for manufacture of uranium tetrafluoride (UF_4), DU derby, DU cast billets, ammonium paratungstate (APT), and tungsten powder would have to be procured during the first year of a mobilization period to meet the shortfall in mobilization capacity for these operations.

For the remaining downstream operations (starting with rolling or extrusion for DU and with blending of alloy powders for tungsten), there will be additional production facilities

required for both materials at peacetime as well as mobilization production levels. For the ATAC, COMVAT and KEM systems, these facilitization costs for peacetime quantities range from $0.5M if all penetrators were made from DU, to $5.75M if all were made from WA. Corresponding costs for mobilization quantities are $11.25M and $18.8M, respectively.

The production costs of DU and WA penetrators were estimated to be equal for large caliber penetrators. WA penetrators are less costly for small caliber sizes such as the Navy 20mm Phalanx system.

Private sector capacity is adequate to supply DOE identified DU programs during peacetime; however, during mobilization, there is no excess capacity available for DOE programs. Maintaining the UF_4 and derby manufacturing capabilities at the DOE Fernald facility is recommended to correct both DOE and DOD mobilization shortfalls, provided environmental concerns don't prevent this.

Short term workloading problems in the DU manufacturing base were examined. There are DOE programs which may provide near term requirements to workload the private sector. A recommendation was made to foster DOD/DOE discussions to firmly establish these quantities and timeframes.

Environmental/Health Factors

The overall conclusion of the environmental/health investigation is that DU and WA are acceptable materials for use as KE penetrators with regard to human health and the environment. The environmental effects of both materials are rather low when appropriate controls are used. Human health risks are manageable to an acceptable level through proper industrial hygiene controls and monitoring, field practice and doctrine, and medical surveillance. The environmental effects of WA and DU munitions have not been fully characterized by the scientific community and should be investigated.

There are advantages of an environmental nature to WA over DU. See Chapter IV for a listing of these advantages. However, the significance of these advantages can only be determined after the thorough characterizations of DU and WA munitions recommended in this report are complete.

Decontamination and disposal (D&D) at manufacturing and test sites, as well as low level waste disposal, will become significant factors in continuing DU operations in the near future.

Life Cycle Costs

Available cost data were analyzed to compare life cycle costs for DU and WA penetrators for each future weapon system. Rough order of magnitude (ROM) cost differentials over a ten year production period were considered in the following areas: R&D; stockpile; facilitization; manufacture; operations and support (O&S); and demilitarization (demil).

The cost drivers identified were: R&D required to improve WA performance (ATAC only); stockpile additions for mobilization (favors DU); possible manufacturing cost differential for COMVAT (would favor WA); and demil (favors WA). The overall life cycle cost differential favors DU by a significant amount for ATAC. For KEM, the cost differential is essentially zero. The cost differential for COMVAT is sensitive to the relative manufacturing costs for the two materials, and ranges from zero to a significant amount in favor of WA.

Significant data gaps exist in this cost analysis due to both time constraints and lack of available data. Estimates for testing, safety monitoring, O&S and demil cost differentials were primarily drawn from previously developed 25mm data. Application of this data to future systems is questionable, especially in light of changing regulatory requirements. Good data on demil procedures and costs are not available.

Overall Recommendations

1. Continue to develop maximum achievable performance from DU penetrators for the ATAC system. This recommendation is considered to be in compliance with DLAM 4145.8/AR 700-64, Radioactive Commodities in the DOD Supply Systems, April 1985, which requires that "use of radioactive materials in items of supply be kept to a minimum consistent with DOD needs."

2. Continue to develop WA penetrators for the COMVAT system, but consider initiating "dual material" development in early 6.3 R&D.

3. For the KEM system, no material recommendation is made, since the performance analysis conducted for this study assumed penetrator and weapon parameters which were not provided by, nor approved by, PM LOSAT. Further analysis, with approved system parameters, should be performed prior to making a material selection.

4. Type Classification, for Foreign Military Sales, of a 120mm WA round similar to the M829 is recommended. This action would provide further incentive to support continued WA material development and projectile design. It would also broaden the penetrator industrial base, for which mobilization shortfalls have been identified.

5. Increase the national stockpile of tungsten concentrate if penetrators are to be made from WA.

6. Pursue further DOD/DOE cooperation in addressing both near term and mobilization related DU production base concerns.

7. Establish a centralized KE penetrator office with authority and funding to provide overall life cycle management of these munitions. The rationale and proposed functions of this office are provided in Chapter VI.

A summary of the report's physical layout is provided here to aid in locating portions of interest. The report consists of six chapters and four appendices. It is bound in two separate sections as follows:

- Chapters I through VI and Appendices A through C.

- Appendix D, detailed environmental and health considerations, is bound separately due to its size.

TABLE OF CONTENTS

for the

KE Penetrator Long Term Strategy Study

		Page
	Executive Summary	i
	Table of Contents	vi
	List of Tables and Figures	xii
Chapter I	BACKGROUND, SCOPE AND APPROACH	
I.1.	Background	I-1
I.2.	Scope	I-2
I.3.	Approach	I-3
Chapter II	PERFORMANCE CONSIDERATIONS	
II.1.	Introduction	II-1
II.1.a.	Threat Analysis	II-1
II.1.b.	Performance Analysis	II-1
II.1.c.	Emerging Technologies	II-2
II.2.	Recommended Technology Development	II-20

Chapter III INDUSTRIAL BASE CONSIDERATIONS

III.1. Introduction III-1

III.2. Quantity Requirements Analysis III-2

III.2.a. Peacetime Requirements III-2

III.2.b. Mobilization Requirements III-3

III.3. Material Availability III-4

III.3.a. Tungsten Availability Considerations III-4

III.3.a.(1) World Reserves III-4

III.3.a.(2) Concentrate Production III-4

III.3.a.(3) Peacetime Outlook for Supply of Concentrate III-12

III.3.a.(4) Mobilization Outlook for Supply of Concentrate III-12

III.3.a.(5) Ammonium Paratungstate (APT) Capacity III-14

III.3.a.(6) Tungsten Powder Capacity III-14

III.3.b. Depleted Uranium Availability Considerations III-16

III.3.b.(1) UF_6 Supply III-16

III.3.b.(2) UF_4, Derby & Cast Metal Capacity III-16

III.3.b.(2)(a) Sequoyah Fuel III-19

III.3.b.(2)(b) Nuclear Metals III-19

III.3.b.(2)(c) Aerojet Ordnance Tennessee III-19

III.3.b.(2)(d)	Manufacturing Sciences Corp.	III-19
III.3.b.(2)(e)	Feed Materials Production Center (FMPC)	III-19
III.3.b.(2)(f)	Y-12	III-19
III.3.b.(2)(g)	Eldorado	III-19
III.4.	Starting Material Quantity Requirements	III-20
III.4.a.	Peacetime Quantity Requirements	III-20
III.4.b.	MOB Material Quantity Requirements	III-23
III.4.c.	Stockpile/Facility Costs for MOB Material	III-27
III.4.d.	Excess Depleted Uranium Capacity Available for Other Requirements	III-30
III.5.	Manufacturing Facility Requirements	III-31
III.5.a.	Existing Facilities for DU Penetrators	III-31
III.5.b.	Existing Facilities for Tungsten Penetrators	III-31
III.5.c.	Peacetime Requirements	III-31
III.5.c.(1)	ATAC Facilities	III-33
III.5.c.(2)	COMVAT Facilities	III-33
III.5.c.(3)	KEM Facilities	III-33
III.5.c.(4)	M919 Facilities	III-33
III.5.c.(5)	105/120 Facilities	III-34

III.5.d.	Mobilization Requirements	III-34
III.6.	Production Cost Comparisons	III-34
III.7.	Industrial Base Analysis Conclusions	III-39
	Industrial Base Analysis References	III-40
	Attachment A - Process Descriptions	III-41

Chapter IV ENVIRONMENTAL CONSIDERATIONS

IV.1.	Summary of Findings and Recommendations	IV-1
IV.2.a.	Overall Findings	IV-1
IV.2.b.	Preliminary Analysis of Long Range Health Risks at Test Sites	IV-1
IV.2.c.	Generic Risk Assessment Findings	IV-2
IV.2.d.	Generic Risk Assessment Conclusions	IV-5
IV.2.e.	Manufacturing Sites Findings	IV-6
IV.2.f.	Manufacturing Sites Recommendations	IV-7
IV.2.g.	Test Range Findings	IV-7
IV.2.h.	Test Range Recommendations	IV-8
IV.2.i.	Recycle and Decontamination Findings	IV-8
IV.2.j.	Recycle and Decontamination Recommendations	IV-9
IV.2.k.	Low Level Waste Findings	IV-9
IV.2.l.	Low Level Waste Recommendations	IV-10

Chapter V	COST ANALYSIS	
V.1.	Introduction	V-1
V.2.	R&D Cost Differential	V-1
V.3.	Stockpile Cost Differential	V-2
V.4.	Facilitization for Manufacturing-Cost Differential	V-6
V.5.	Manufacturing and O&S Cost Differentials	V-9
V.6.	Demil Cost Differential	V-9
V.7.	Cleanup Cost Differential	V-12
V.8.	Total Life Cycle Cost Differential	V-14
V.9.	Cost Differential Summary	V-14
	References for Chapter V	V-17
Chapter VI	CONCLUSIONS AND RECOMMENDATIONS	
VI.1.	Conclusions	VI-1
VI.1.a.	Performance Conclusions	VI-1
VI.1.b.	Industrial Base Conclusions	VI-2
VI.1.c.	Environmental Conclusions	VI-3
VI.1.d.	Cost Analysis Conclusions	VI-5
VI.2.	Recommendations	VI-6
VI.2.a.	System Recommendations	VI-6
VI.2.b.	Industrial Base Recommendations	VI-7
VI.2.c.	Environmental Recommendations	VI-7

VI.2.d.	Performance Related Recommendations	VI-9
VI.2.e.	Overall Recommendations	VI-10
Appendix A	TEST AND EVALUATION CONSIDERATIONS	A-1
Appendix B	CONTRACTOR COMPARISON OF ENVIRONMENTAL RISKS (TEST RANGES)	B-1
Appendix C	GLOSSARY	C-1
Appendix D	CONTRACTOR ENVIRONMENTAL REPORT (Note: App D is separately bound)	(See App D for paging)

LIST OF TABLES AND FIGURES
for the
Kinetic Energy Penetrator Long Term Strategy Study

TABLES	TITLE	PAGE
II-1	(Table II-1 Deleted)	
II-2	Depleted Uranium Alloy Dev. Programs	II-9
II-3	Tungsten Initiative Program	II-12
II-4	Tungsten Alloy Development Programs	II-14
II-5	Representative Tungsten Alloys	II-16
II-6	Ballistic Performance - Standard Materials	II-18
III-1	World Reserves Base for Tungsten	III-5
III-2	Tungsten Concentrate Sources During Mobilization Period	III-13
III-3	Yearly North American Production Capacities for Depleted Uranium (UF_4 Derby & Casting)	III-18
III-4	Yearly Mob Material Quantity Requirements by Item	III-26
III-5	Peacetime & MOB Yearly Quantity Requirements	III-28
III-6	Stockpile/Facility Costs for MOB Material	III-29
III-7	Peacetime Penetrator Facility Costs	III-32
III-8	MOB Penetrator Facility Costs	III-35

III-9	Peacetime & MOB Facility Cost for Various Material/Item Mixes	III-36
III-10	DU Versus WA Cost Comparison	III-37
III-11	Generic Processes for Penetrator Manufacture	III-42
V-1	R&D Cost Differentials	V-3
V-2	DU Stockpile for Mobilization	V-4
V-3	Tungsten Stockpile for Mobilization	V-5
V-4	Stockpile Cost Differential for MOB	V-7
V-5	Facilitization Cost Analysis	V-8
V-6	Facilitization Cost Differential	V-10
V-7	Manufacture and O&S Cost Differential	V-11
V-8	Demil Cost Differential	V-13
V-9	Total Life Cycle Cost Differential	V-15
A-1	Milestones (Superbox)	A-6

FIGURES	TITLE	PAGE
II-1	Electric Guns vs Powder Guns	II-3
II-2	Depleted Uranium Alloy Mechanical Properties	II-10
II-3	Tungsten Alloy Mechanical Properties	II-15
II-4	Ballistic Enhancement Initiative for Tungsten	II-22
III-1	Tungsten Concentrate Producers 1988	III-7
III-2	Price History of Tungsten Concentrate	III-8

III-3	Tungsten Concentrate Consumers 1988	III-9
III-4	World Concentrate Production by Year	III-10
III-5	Components of U.S. Tungsten Supply 1980 to 1988	III-11
III-6	U.S. APT Supply 1980 to 1988	III-15
III-7	U.S. Tungsten Powder Production	III-17
III-8	Yearly Peacetime Requirements of UF_4 and Derby by Item	III-21
III-9	Yearly Peacetime Requirements of Cast Metal by Item	III-22
III-10	Yearly Peacetime Requirements of Tungsten Concentrate by Item	III-24
III-11	Yearly Peacetime Requirements of APT/Tungsten Powder by Item	III-25
A-1	CSTA DU Catch Box Facility	A-4
A-2	Superbox Artist's Concept	A-7
A-3	Superbox Diagram	A-8
A-4	Superbox Diagram	A-9
A-5	Superbox Diagram	A-10

(See Appendices B and D for lists of additional tables and figures in those Apendices.)

CHAPTER I

BACKGROUND, SCOPE AND APPROACH for the KE Penetrator Long Term Strategy Study

1. Background

a. This study addresses the following question posed by the Deputy Assistant Secretary of the Army for Research Development and Acquisition (Dep ASA/RDA) in January, 1989: "What is the best, long term strategy for the U.S. Army in the choice of KE penetrator materials?"

In tasking the Deputy Chief of Staff for Ammunition (DCS for Ammo) at the Army Materiel Command (AMC) to take the lead in addressing this question, the Dep ASA/RDA referred to the increasing burden and changed resource situation associated with the current KE penetrator material, depleted uranium (DU). These DU related concerns were based on several assumptions:

1) Strategic resource availability forecasts have changed since the original DU investment decision was made.
2) Technical advances in alternate materials have been made, which provide enhanced launch characteristics and terminal ballistics.
3) The manufacture, testing and demilitarization (demil) of DU penetrators will become increasingly more complex, costly and subject to severe Environmental Protection Agency (EPA) restrictions.
4) It is highly desirable to fire some service ammunition in training, and economically desirable to fire obsolete service ammo (with minimal rework) in training.

To varying extents, the above assumptions have been examined during this study.

Several additional assumptions lay behind these DU concerns which have not been addressed:

1) There will be increasing pressures to pursue cooperative agendas with our NATO and non-NATO allies which may have some influence on penetrator material selection.
2) Foreign military sales will often require alternate materials. Related to this is the assumption that overseas sales or deployment of DU will be subject to increasing political sensitivity and product liability.

An examination of the validity of these latter two assumptions, and the related impacts on material recommendations, was considered beyond the resources and scope of this study.

b. In late April, 1989, the DCS for Ammo tasked the U.S. Army Armament, Munitions and Chemical Command (AMCCOM) with establishing an AMCCOM Task Group to address the Dep ASA/RDA's question, with emphasis on three major areas of investigation:

1) Industrial base impacts
2) Environmental concerns
3) Performance considerations

A senior level Steering Panel was established, chaired by the Assistant DCS for Ammo, to guide the efforts of the Task Group, and other related efforts, toward developing a strategic long range plan for KE penetrators. It should be noted that the title AMCCOM Task Group is not completely accurate, since a significant portion of the effort was performed by the Ballistics Research Laboratory (BRL) within the U.S. Army Laboratory Command (LABCOM).

c. With AMC and Steering Panel guidance, the Task Group developed a Study Plan and initiated a five month effort in June, 1989. A draft Final Report was completed in December 1989, and was distributed to DU and Tungsten penetrator manufacturers for comment in February 1990. Since the draft report was distributed, many helpful and constructive comments were received from industry representatives. This report presents the unclassified and non-proprietary findings of the Task Group's investigations, adjusted to reflect many of those comments.

2. SCOPE

a. The study considered recommendations for material selection for the KE penetrators to be used in three future Army weapon systems which are scheduled to be fielded during the 1995-2000 timeframe. These are: Advanced Tank Cannon (ATAC) System for the Block III tank; Combat Vehicle Armament Technology (COMVAT) Program for the Future Infantry Fighting Vehicle (FIFV); and the Kinetic Energy Missile (KEM) for the Line of Sight Anti-Tank (LOSAT) System.

b. Other uses of the penetrator materials, such as armor, DOE programs, explosively formed penetrators (EFP) and commercial applications were considered only from the vantage of their impact on raw material usage and production capacity.

c. The overall objective of the study was to provide recommendations for KE penetrator material selection for each of these future weapon systems. Plans and rough order of magnitude (ROM) costs to implement these recommendations were also to be provided.

3. APPROACH

a. All possible material alternatives which would satisfy future requirements were considered, but most of the study effort was directed toward evaluation of the advantages and disadvantage of DU and tungsten alloys (WA). Past and current KE penetrator performance and production quantity requirements were reviewed to establish a baseline for examining future requirements. Each material was investigated to assess its relative merits in the areas of performance vs. the future threat, industrial base considerations, environmental impacts, and life cycle costs for each weapon system considered. Chapters II through V provide the findings and conclusions in each of these areas, respectively. Chapter VI presents the overall conclusions and recommendations of the study. Much of the threat, performance and quantity requirement information utilized in the study is classified and is only referred to in this report.

b. During the course of the study, the Steering Panel raised several issues closely related to the Long Term Strategy Study, which have been addressed as follows:

1) Test and Evaluation - Interest was expressed in identifying means of reducing the amount of DU test firings by application of statistical process control (SPC) and other methods. Information provided by the AMC Quality Assurance (QA) Office on this topic is included in Appendix A. Also included there is information on the TECOM Superbox and catchboxes.

2) DU base workloading - Near term workloading concerns within the DU production base were discussed and evaluated with respect to DOD and DOE quantity requirements. Results of the evaluation are considered in the study's recommendations, but details are not included in this report since they are competition sensitive.

c. To address the major areas of study interest, the AMCCOM Task Group was formed into four sub-groups. The personnel resposible for the data gathering and reporting within each area are as follows:

1) Industrial Base Considerations

Mr. Duane Gustad (ARDEC, SMCAR-CCH-P)
Mr. Michael Smurla (PBMA, AMSMC-PBM-K)
Mr. Gerard Voorhis (ARDEC, SMCAR-CCH-P)
Mr. David Dakan (AMCCOM, AMSMC-IRC)

2) Environmental Considerations

Mr. Thomas McWilliams (PBMA, AMSMC-PBM-A)
Mr. George O'Brien (PBMA, AMSMC-PBM-D)

3) Performance Considerations

Mr. Louis Giglio-Tos (BRL, SLCBR-TB-P)
Mr. Konrad Frank (BRL, SLCBR-TB-P)
Mr. Stanley Waxman (ARDEC, SMCAR-AET-M)
Dr. Sheldon Cytron (ARDEC, SMCAR-AET-M)
Mr. Paul Gemmill (ARDEC, SMCAR-CCH-V)
Mr. Sheldon Rachlin (ARDEC, SMCAR-FSS)
Mr. John McDonald (ARDEC, SMCAR-ASF)
Mr. Robert Testa (ARDEC, SMCAR-CCS)
Mr. Owen Saucyn (ARDEC, SMCAR-CCS)

4) Cost Analysis

Mr. Richard Rhinesmith (ARDEC, SMCAR-ASH)
Ms. Joyce Kufel (PBMA, AMSM-PBM-K)

Team Leader - Mr. Michael Danesi (ARDEC, SMCAR-CCH)

In addition to these team members, valuable assistance was provided by several other members of the Terminal Ballistics Division of BRL, and by various offices within PBMA, ARDEC, HQ AMCCOM and MICOM. The environmental investigations were supplemented by the contractual efforts of Science Applications International Corporation (SAIC), whose comprehensive report is summarized in Chapter IV. Appendix D contains a generic risk assessment and summary report from SAIC. Radiological Assessments Corporation provided a preliminary analysis comparing the long range health risks of DU and WA contamination of test ranges and battlefields. Their report is included as Appendix B. Finally, the DU and WA manufacturers provided data on their materials, processes and capabilities, without which the study could not have been completed.

CHAPTER II

PERFORMANCE CONSIDERATIONS
for the
KE Penetrator Long Term Strategy Study

1. Introduction

The ability of DU and alternate KE penetrator materials to defeat future threats associated with the ATAC, COMVAT and KEM weapon systems will be discussed in this chapter. Although the intent of the study was to analyze all acceptable alternates to DU, no material other than tungsten alloy (WA) was identified which might satisfy the performance requirements of these three weapon systems, given the launch and material technologies expected to be available for fielding prior to the year 2000. Los Alamos National Laboratory is experimenting with several DU-WA composites which they feel show promise of performance benefits over either material individually. Since this alternative would probably not help in solving the perceived problems associated with DU referred to in Chapter I, and since testing data is limited, it was not considered as a third alternative for purposes of this study.

The performance investigation was conducted in three phases. First, an assessment was made of the appropriate threat to use for study purposes for each weapon system. Next, a performance analysis was conducted by BRL, which considered state-of-the-art DU and WA material performance vs. the threat. And lastly, an assessment was made of the emerging technologies for penetrator materials and future launch capabilities which may have an impact on BRL's performance analysis, and, thus, on material choice. These three areas of investigations are discussed below.

a. Threat Analysis

1) The objective of this portion of the investigation was to determine, for study purposes, the appropriate threat to be used by BRL in their performance analysis. The guidance provided by the Steering Panel was to utilize appropriate range targets, as determined by the threat community. Rolled Homogeneous Armor (RHA) equivalents were to be used as a back-up definition of the threat for each system. Both range targets and RHA were eventually used by BRL in their analysis.

2) Details of the approach and conclusions of the threat analysis are classified and are not included in this report. The range targets used in the performance analysis were concurred in by the office of the Deputy Chief of Staff for Intelligence (DCSINT) as representing the appropriate system threats at the time of BRL's performance analysis (October 1989).

b. Performance Analysis

1) Pertinent system parameters for the ATAC and COMVAT systems were provided to BRL by the appropriate program offices.

These parameters were unavailable for the KEM/LOSAT system at the time of the study, but BRL was able to conduct the analysis using an assumed geometry and velocity profile.

2) Details of the BRL performance analysis are classified and are not included in this report. In summary, BRL's analysis shows that KE systems using DU penetrators outperform those with WA penetrators when the same system constraints are applied. The specific item designs analyzed also show that this performance gap may be overcome to some extent by using higher technology projectile designs or launch mechanisms for WA than those assumed in the analysis. On the other hand, as long as requirements dictate extracting the maximum possible performance of systems like KEM, ATAC and COMVAT, the material of choice will remain DU.

c. Emerging Technologies

This section provides the findings of the study in investigating the improvements in material performance and launch technologies which may be expected to be available to the ATAC, COMVAT or KEM weapon systems by their respective fielding times. An evaluation is made of the likelihood that these technologies will change the levels of performance achievable by each penetrator material as estimated by BRL in their performance analysis.

1) Future Launch Technology

a) There are five launch systems considered in this study for possible application of their technology to ATAC, COMVAT and/or KEM by the 1995 - 2000 time frame, namely: Rocket Assisted Kinetic Energy (RAKE), X-Rod, Liquid Propellant Gun (LP), Electrothermal Gun (ET), and Electromagnetic Gun (EM).

All five systems are characterized by delivering penetrators with much higher terminal velocity than the weapons they will replace. To help convey the relative differences between the distinctly different systems, Figure II-1 shows three curves depicting the relative differences on scaleless coordinates. The graphs tend to convey the quantum leap in muzzle energy potentially derived by the future weapon technology.

In the BRL analysis, WA performance was marginal or failed to defeat certain targets using specific guns. With these five new weapon technologies, much higher terminal velocities and higher mass penetrators will be launched, producing higher kinetic energy upon target impact. Consequently, the kinetic energy delivered to the target is expected to be overwhelming enough to defeat the most advanced foreign threat as it is conceived at this time. The question this portion of the study attempts to address is "will these technologies be available, with acceptable risk levels, within the fielding time frame of the ATAC, COMVAT and KEM systems?"

RAKE will provide an unguided extended range to the KE round for the 105mm, M68 tank gun system. It is a cannon launched KE projectile containing a DU penetrator, with a rocket motor booster. Maintaining accuracy in this type of ammunition is usually a problem; and being in its early stage of development, acceptable

ELECTRIC GUNS V:S POWDER GUNS

This graph is intended to convey the relative proportionality of performance between the three distinctly different gun technologies.

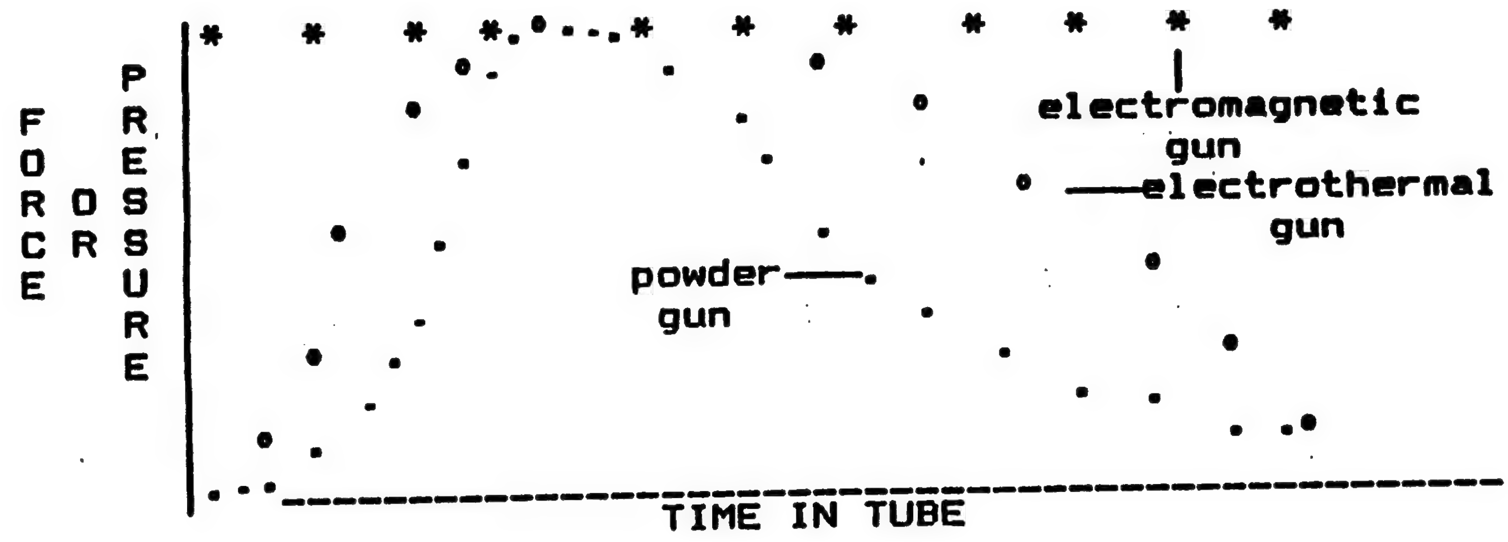


Figure II-1

accuracy has yet to be demonstrated by RAKE at the required terminal velocity and range. If the RAKE system were developed to its full potential, application of this technology to the ATAC gun system would provide a substantial increase in terminal velocity. However, the risk associated with applying RAKE technology to improve the ATAC system performance beyond that which was estimated in BRL'S analysis is considered high, due primarily to the accuracy problems mentioned above.

The X-rod program is relatively new. It is a 120mm cannon-launched KE round, rocket motor boosted, and guided to target. There are two competitive contractors with different guidance philosophies: one has command guidance to the target; the other is a (fire-and-forget) terminal homing guidance. In this type of system, the development of the guidance system to withstand the severe setback forces and maintain corrective guidance during high flight perturbations are difficult problems. If a significant technological advance is discovered during the very early stages (next five years) of X-rod development which may be transferred to the RAKE, perhaps it will enhance the RAKE sufficiently to upgrade its capability before the year 2000. This technological transfer is not a likely expectation by that timeframe.

The liquid propellant (LP) gun, also known as the high performance liquid propellant gun (HPLPG), program has been with us for a long time. The program has been judged by many to have been underfunded. Repeatability was a problem of the past, but has been resolved. The basic principles of the LP concept have been demonstrated with 125 firings in a 155mm artillery weapon. In a recent rapid fire demonstration, 10 rounds were fired in six seconds in a 30mm gun with breech pressures and muzzle velocities comparable to those in the present 105mm and 120mm guns. More than 500 rounds have been shot in the 30mm gun to date. The program director at ARDEC has high confidence that, if funded, a 120mm LP tank gun could be developed and ready for production by 1997. This assessment is considered optimistic. Such a tank gun is predicted to at least equal the current ATAC muzzle velocity requirement. Comparing a 120mm LP gun with the ATAC weapon system, the LP gun has at least six distinct advantages: a) increased ammunition capacity (raised from 4[illegible] to 66 rnd./tank), b) insensitive mono-propellant, c) can use existing projectiles, d) can be installed in an ATAC gun mount, e) very compatible to auto-load, and f) exceptionally high rate of fire (KE 20/min., HEAT 13/min.). However, since application of the 155mm technology to tank systems appears to be a low intensity effort, it is judged by this study that a high risk prevails in applying the LP technology to ATAC by its fielding time frame.

The ET gun -- still in early R&D -- departs from the conventional method of igniting and burning of solid propellant in guns, and introduces a revolutionary technical launch concept. A major difficulty is the development of a suitable power supply. Also, high rate of firing limitations, repeatability and barrel wear must be addressed. On the other hand, present tank guns can most

likely be used with the new system. Referring to **Figure II-1**, it becomes evident that the ET gun could deliver much more energy under the pressure-time curve; consequently, much higher muzzle energy is achieved with a softer launch than that of the conventional powder gun. This performance is accomplished through an electrical discharge creating a plasma of hot, expanding gases (from solid or liquid propellant). Sub-scale engineering ET shots are to commence in 3QFY90. The predicted performance alludes to the proposition that heavier penetrators, having high L/D ratios, can be launched due to the softer set-back forces. If, in the near future, the ET program enters an accelerated status for application to the ATAC system, it is considered feasible that an ET tank-mounted gun could be fielded near or shortly after the turn of the century.

The EM gun is even a greater departure from the conventional powder gun than the ET gun. It launches the projectile on an electromagnetic principle, where no solid or liquid propellants are involved. There are two different methods of generating the magnetic field and applying the resultant magnetic force to the projectile. One method is to generate the field by a series of coils around the gun barrel; projectile motion is produced much the same way an electrical solenoid functions. In this method, however, the gun would become quite heavy and the barrel may be bulky due to the coils. The competing method is to charge two rails of opposite polarity, and with very high current passing between the rails through the projectile base, a strong magnetic field is developed imparting motion to the projectile. In this method, though, rail arcing and deterioration is a significant problem. Both systems require very high capacity power supplies and high capacity electrical energy storage capability. The big payoff is a constant high accelerating force on the projectile, which results in super high muzzle velocity far exceeding that of any gun heretofore conceived. Another big advantage is the potential for increased ammunition volume on fighting vehicles (made possible by eliminating the cartridge case). Once fully developed, this system will achieve what is truly a hyper-velocity performance level. The EM program contains very high risks, but will have a proportionally high return once either method is fully developed and fielded. It is reasonable to expect this gun system will take several years longer to develop than the ET system.

b) In addition to the above five systems, some additional technologies were also taken into account. The following programs may have potentially useful technologies, but are presently inhibited for a variety of reasons (e.g. under-funded, lack of adequate visibility, reached a temporary impasse, or due to a shift in program priority.) Other technologies were not investigated during this study due to difficulty in acquiring pertinent information.

Traveling charge ammunition has an attractive theoretical advantage over the present conventional ammunition, in terms of higher muzzle velocity at a minimal cost. There have been several independent investigations of the basic theory, but it has yet to be demonstrated as functionally reliable and practical to produce in a production environment. The latest traveling charge tests conducted in the 120mm tank gun increased the muzzle velocity by only a

minimal amount over a typical conventional round; with optimization, the prediction is, perhaps, a total of 10% increase. In addition, there are several technical problems still to be addressed, such as the development of a new propellant with a burn rate which exceeds anything that now exists. It appears that these high technical risks are excessively disproportionate to the potential payoff, and additional funding for continued work is in doubt.

Segmented penetrators provide a theoretical deeper penetration advantage over solid penetrators of the same mass and diameter. There has been difficulty in demonstrating the added penetration performance on a dependable basis for service rounds; maintaining alignment of the series of segments while passing through the target may be the problem. It is not anticipated that the segmented penetrator technology will have an impact on the three primary systems (ATAC, COMVAT & KEM) and their companion ammunition cited above, within their fielding timeframes.

c) An additional area of development that could result in a boost in terminal performance is the optimization of sabot material and design. Such a gain can be realized by reducing ancillary weight; as inbore weight goes down, muzzle velocity goes up. Weight reduction of the sabot may be achieved in three ways: alternate material; new configurations; or a combination of both. Within the family of sabot configurations, there are two different geometric types used in high performance tank KE ammunition, the saddle, and ring sabots. U S Army ammunition predominantly uses double ramp, saddle sabots. The most recent evolution in double ramp, saddle sabot design is with composite sabot material, which has demonstrated significant weight reduction. This type of technology has already been considered in BRL's performance analysis, although no allowance was made for optimizing sabot design for WA penetrators.

Through a DARPA program, Battelle Columbus Laboratories is developing a ring sabot based on a Soviet design, and expects comparably improved performance. Range ballistic tests of full scale ammunition with the Battelle ring sabot are ongoing. If the test range data shows significant performance improvement, it is conceivable that such a design could be applied to the ATAC and subsequent ammunition. In addition, optimization of sabots specifically designed for use with improved WA penetrator materials (discussed in Section II.2 below) could enhance system performance beyond that considered in the BRL performance analysis. However, to date there is little data available to either support or refute this idea; further design work and testing are justified.

d) Launch Technology Findings:

(1) The launch technologies investigated could impart large energy increases on target. If successfully applied to the ATAC or COMVAT weapon systems, the margin of overmatch for WA penetrators presented in the BRL performance analysis could be increased to a completely acceptable level. However, the risk associated with these major improvements becoming available for fielding during the period 1995 - 2000 is considered high.

(2) Optimization of sabot/penetrator designs for WA penetrators warrants future development efforts.

2) Kinetic Energy Penetrator Materials

This section will address developments in penetrator rod materials and assess the emerging technologies in this area.

In the past several years, a new emphasis on developing better penetrator rod material has surfaced within the DOD community. As a result, various RDTE programs are ongoing to insure that improvements in the mechanical properties of depleted uranium (DU) alloys can still translate into enhanced ballistic performance. The concerns with DU material mentioned in Chapter I and discussed further in Chapters III-VI below have also motivated an appraisal of tungsten alloy development in the industry and likewise fostered several DOD sponsored programs to devise means by which tungsten could be "ballistically" improved. The aim of these programs is to demonstrate the ability to develop an effective tungsten alloy capable of ballistically performing as well as the present depleted uranium alloys.

This section will report on the present developmental status of the only two reliable kinetic energy (KE) penetrator materials, depleted uranium and tungsten heavy alloys. Although other comparable high density materials (e.g., Re, Au, Pt) exist that can possibly serve as kinetic energy penetrator materials, their developmental immaturity and high cost preclude their being given serious consideration. However, in one case - the exploratory development of depleted uranium/tungsten reinforced composites - there is some interest. Initially, DARPA funded programs focused on tungsten wire reinforced composites. These materials ballistically did not show sufficiently enhanced performance to justify their high fabrication costs. More recent studies being undertaken by LANL under the DOD/DOE Munitions Program are emphasizing cast composite structures that are more cost effective. An assessment of the ballistic performance of these new materials must await further process development and property characterization.

An assessment, however, will be made as to whether presently maturing efforts in depleted uranium and tungsten alloys would substantially change the BRL Performance Analysis discussed above, which evaluates our capabilities to defeat the target threats envisioned by the turn of the century. Considerations are also given to the technical barriers that need to be addressed to clarify our understanding of penetrator-target interactions. Special consideration is given to furthering studies which would eventually allow reintroducing tungsten alloys into the family of large caliber kinetic energy penetrator materials.

a) Present Materials Technologies

This segment of the report on emerging technologies will discuss those state-of-the-practice materials considered to be sufficiently matured to be readily incorporated into the weapon system developments under discussion in the report. Mention will also be made of material developmental efforts of a longer range. These longer range developments, if properly nurtured to demonstrate sufficient promise, might make available materials that could be incorporated by the year 2000 into these weapons systems as product improvements. The major participants in the material programs will be listed together with the technical approaches being studied. Depleted uranium alloys will be discussed first, followed by tungsten alloy development.

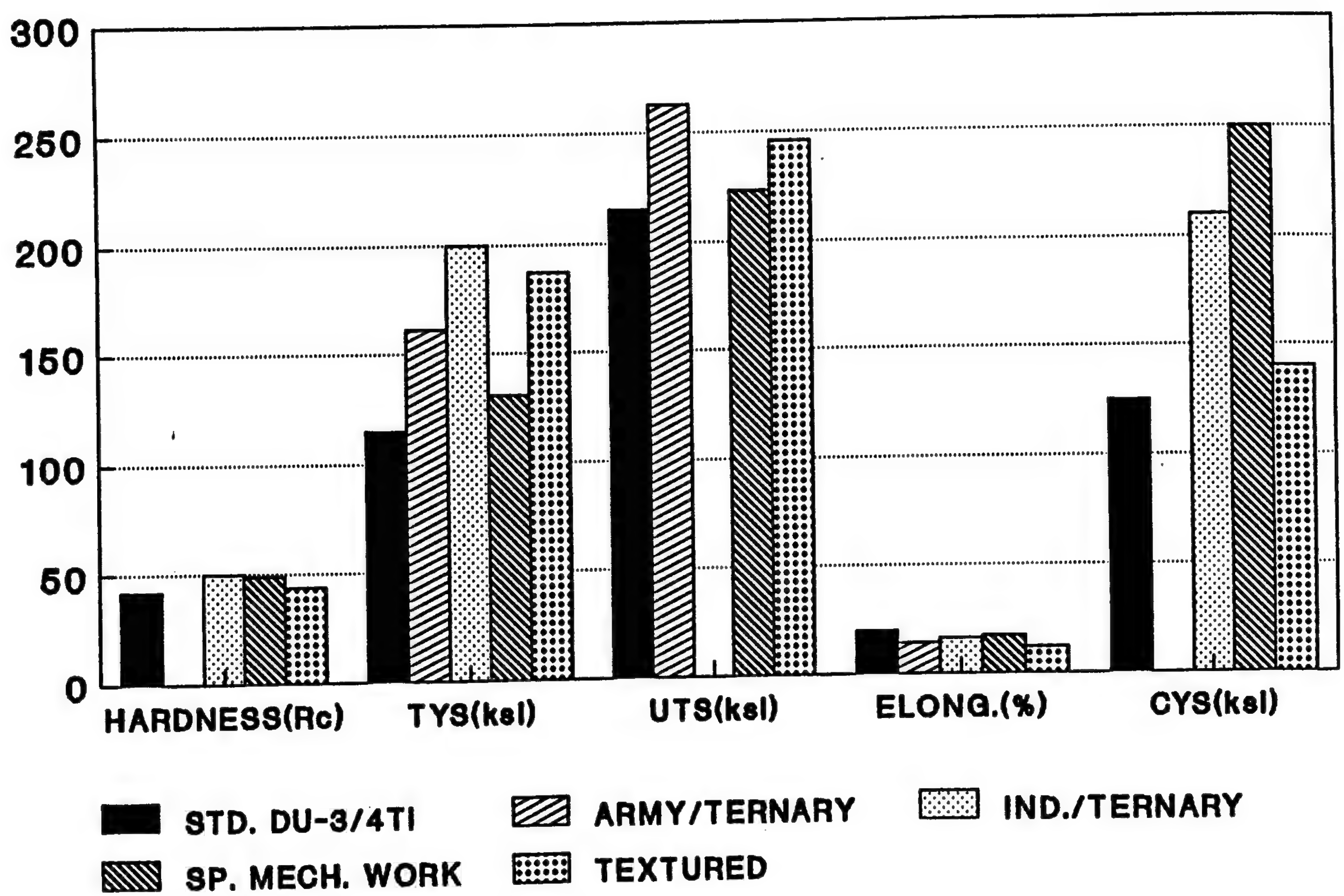
(1) Depleted Uranium Alloys

The first large caliber kinetic energy projectile (M774-105mm) that utilized a depleted uranium alloy was introduced into the field in the late 1970's. The penetrator material was a depleted uranium, 3/4 weight percent titanium alloy conventionally vacuum cast, heat treated and precipitation strengthened (aged) to give the desired mechanical properties. This alloy has been the mainstay for all present large caliber anti-tank kinetic energy penetrator rounds (e.g., M829-120mm, M833-105mm) and for the follow-on developmental rounds in the 105mm and 120mm systems. Maturing material development programs all have as a basis this standard cast binary alloy. Program approaches differ in either the addition of a ternary element (to enhance mechanical strength by a solid solution strengthening mechanism) or in developing thermo-mechanical working schemes to impart additional strengths to the DU alloy. Table II-2 lists the current DU programs, the program participants and the technical approaches under study. The approaches in parentheses are the long term efforts. These programs are not expected to be sufficiently mature by to be confidently considered for transition into the KE weapon systems under consideration in this study. Figure II-2 shows the progressive mechanical property improvements being made by these development programs compared to the standard U - 3/4 Ti alloy. The new ternary element additions impart additional strengths by a solid solution strengthening mechanism. The special mechanical working and textured schemes impart added strength to the standard alloy by unique deformation strengthening mechanisms. Since all these strengthening mechanisms have additive qualities, it is expected that giving

Table II-2 DEPLETED URANIUM ALLOY DEVELOPMENT PROGRAMS

PROGRAM	PARTICIPANTS	TECHNICAL APPROACHES
Exploratory Development	PBMA, ARDEC, BRL, BNW	Special Mechanical Working of STD U-3/4 Ti (Textured DU)
DARPA/Army Armor/Anti-Armor program	ARDEC, Allied-Signal	Cast Ternary Alloys (RST/DU)
Manufacturing Methods and Technology (MMT)	MTL - Aerojet PBMA - Aerojet	Thermo-mechanical Working of STD U-3/4 Ti Alloy.
DOD/DOE Munitions	LANL	(DU - Tungsten Cast Composites)
Industry	NMI, Aerojet	Cast Ternary Alloys Thermo-mechanical Working

FIG.II-2 DU ALLOY MECHANICAL PROPERTIES



(Note: Complete property data not available for all alloys)

the new ternary alloys these special mechanical working treatments would result in the following mechanical properties for a DU alloy (density range of 18.4 - 18.6 g/cc):

300 ksi Comprehensive Yield Strength
250 ksi Ultimate Tensile Strength
175 ksi Tensile Yield Strength
45-50 Rockwell C Hardness

These mechanical properties are substantial improvements over the standard U - 3/4 Ti alloy and can be expected to conservatively provide a 3% to 7% improvement in terminal ballistic performance for RHA penetration (zero obliquity). Similar penetration gains against advanced reactive and complex armors are yet to be projected.

Longer term programs (e.g., composites, RST/DU) that aim to effectively challenge new advanced armor designs are underway to further bolster mechanical property improvements in DU alloys. To date, only fragmentary and inconclusive mechanical property and/or small scale ballistic data are available from these programs to assess their long term potential.

(2) Tungsten Alloys

With the introduction of the first lage caliber depleted uranium kinetic energy penetrator (i.e., 105mm M774) in the late 1970's and the production phase-out of the last tungsten KE penetrator rod (i.e., 105mm M735), further R&D work on tungsten material was markedly reduced. This occured not only at Army laboratories but also at the three principal tungsten alloy developers in the United States (i.e., GTE, Kennametal, Teledyne Firth Sterling). This remained the situation for several years until 1986 when Army interest in tungsten alloys was renewed. With new materials processing technologies being developed throughout the metallurgical industry for improving a broad spectrum of both ferrous and non-ferrous alloys, the exploitation of these new technologies for tungsten was considered a promising approach to further improve tungsten alloys. An Office of Munitions, OSD/ARDEC Tungsten Initiative program was developed to re-examine tungsten alloys. At the September 1986 Tungsten Ordnance Technology Seminar sponsored by the Refractory Metals Association (RMA), an overview of the tungsten initiative program was presented to industry. Table II-3 outlines the objectives and approaches of the program. A complementary BRL/LABCOM-RMA program was also established to address acquiring a ballistic data base on state-of-the-practice tungsten alloys available from the industry.

Table II-3 TUNGSTEN INITIATIVE PROGRAM

Objectives

Explore new/modified processing technologies to provide for improvements in mechanical properties.

Assess new compositions/treatments for enhanced ballistic performance.

Approach

Evaluate modified liquid/solid sintering techniques for tungsten heavy alloys.

Investigate various strengthening methodologies.

Evaluate various thermomechancial processing for enhanced strength and toughness.

Ballistic Data Base Development.

To date, the maturing tungsten heavy alloys being developedd from the various programs are all based on liquid phase sintered (LPS) blended metal powders. The exception being the tungsten filaments under development for aerospace and SDI applications. Table II-4 lists the current programs, the participants and the technical approaches under study. The approaches in parentheses are exploratory in nature. Since these projects rely upon a very limited industrial base, they are not expected to fully mature before the year 2000 unless given a more focused effort. Whether such a focused effort will be forthcoming will depend upon efforts now underway to ballistically assess the newer tungsten alloys developed under the more mature programs. If these new alloys prove to be ballistically deficient, a decision to implement the recommendations of the Army's 1989 Tungsten Coordination Committee to establish such a focused effort would be recommended.

Figure II-3 shows the progressive mechanical property improvements achieved over the industrial standard swaged 90 weight percent tungsten alloy. Table II-5 further characterizes the compositions and processing conditions of these representative alloys. Classified mechanical property data on the DARPA sponsored tungsten alloy development program undertaken at Battelle Columbus show that these materials have similar mechanical strength properties to the 93 WHA (TMP) alloy but higher toughness values. A comparison of the mechanical properties of tungsten (Figure II-3) with depleted uranium alloys (Figure II-2) shows that the properties of the 93% tungsten material have substantially improved and compare favorably with the DU alloys. Regardless of having achieved somewhat comparable mechanical properties, the classified data on terminal ballistic performance of DU and tungsten show, however, a decided material performance gap in favor of DU. Regardless of the density differences between the penetrator alloys, recent findings at BRL appear to indicate that DU possesses specific thermomechanical properties which impart to it unique high strain rate deformation failure modes that give it a major advantage in RHA penetration. A discussion of the ballistic performance of these materials is provided next.

Table II-4 TUNGSTEN ALLOY DEVELOPMENTAL PROGRAMS

PROGRAM	PARTICIPANTS	TECHNICAL APPROACHES
Exploratory Development	ARDEC, BNW, BRL	Special Mechanical Working-93 WA/MW
Tungsten Initiative (RDT&E Technology Base)	ARDEC, BRL	Modified Thermomechanical Processing - 93 WHA/TMP
		(Solid State Sintering)
		(RST/Tungsten)
		(Cast Technology)
		("Designer" Alloys)
LABCOM/RMA	BRL - Industry, MTL	Matrix Modified LPS Alloys
DARPA Armor/Anti-Armor	MTL - GTE, Battelle	Adv. Thermomechanical Processing
Industry	Teledyne Firth Sterling	Modified Liquid Phase Sintered Alloy - 93 WA/SW
		New LPS Alloys - X27X
Aerospace, SDI	NASA/DOE	Tungsten Fiber Reinforced Composites
DOD/DOE Munitions	LANL	(Exp. Mechanical Processing)
		(Exp. Powder Consolidations)

FIG.II-3 TUNGSTEN ALLOY MECHANICAL PROPERTIES

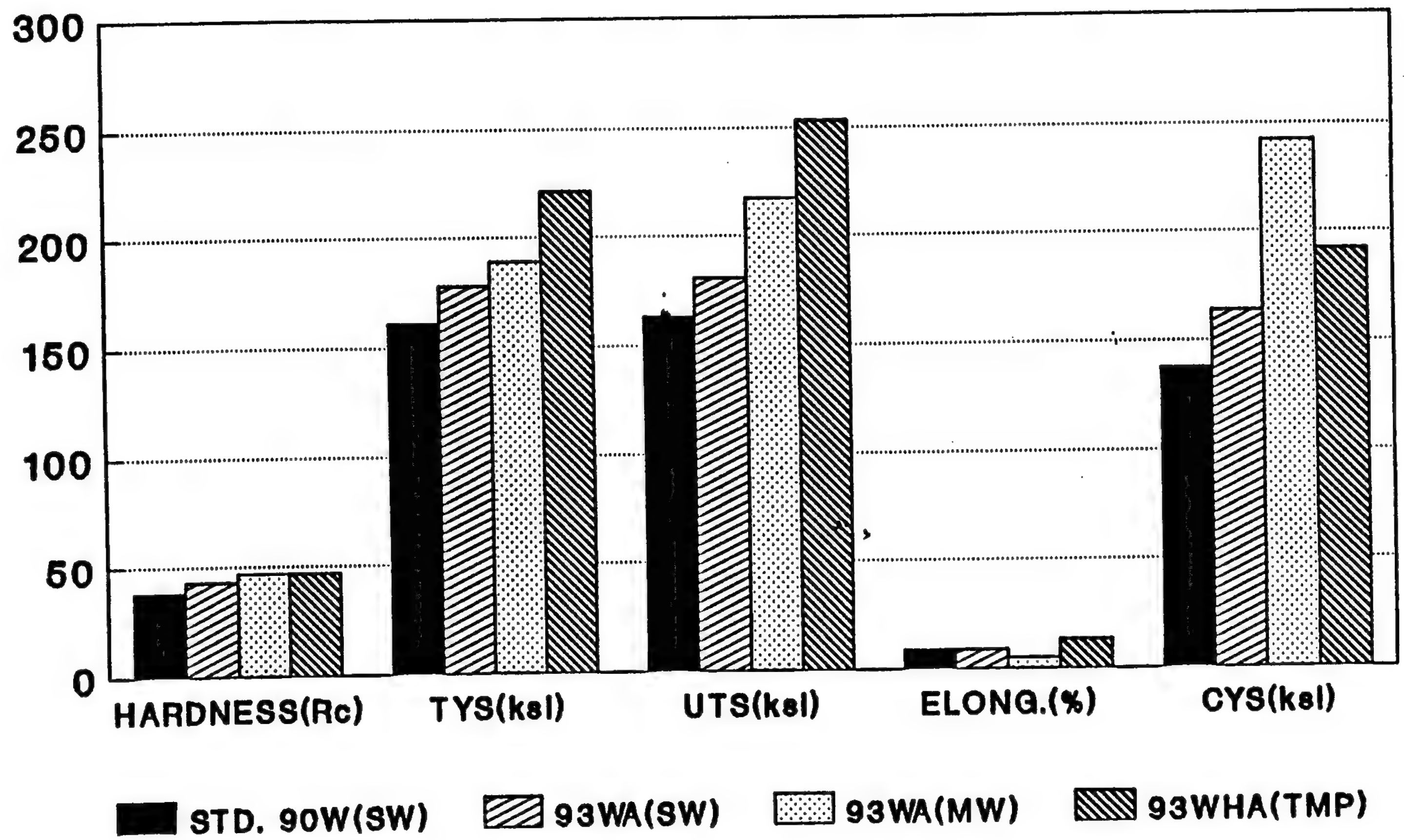


Table II-5 REPRESENTATIVE TUNGSTEN ALLOYS

Designation	Compostion - wt%	Density (g/cc)	Processing
STD 90 W (SW)	90 W, 7 Ni, 3 Fe *[W10]	17.2	LPS, Swaged 20%
93 WA (SW)	93 W, 3.43 Ni, 1.47 Fe, 2.10 Co. *[X21C]	17.7	LPS, Swaged 25%, 400°C age
93 WA (MW)	93 W, 3.43 Ni, 1.47 Fe, 2.10 Co *[X21C]	17.7	LPS, swaged 10%, 400°C age 10% Mechanical work, 500°C age
93 WHA (TMP)	93 W, 2.8 Ni, 1.2 Fe, 1 Mo, 2 Co. *[ARDEC]	17.7	LPS, Extrude 80%, Anneal 1200°C, Multi-Swage 75%, Anneal 800°C.

* [Industry Designation]

(3) Ballistic Performance

With regard to the issue of rod material preference based upon ballistic performanace, there are two schools of thought. One school emphasizes basic terminal ballistic armor penetration, normalized to the maximum degree possible, so as to define inherent material performance differences. Using this concept, a data base is established against a variety of armor designs to show consistent material behavior. In these tests, correlations are sought between ballistic performance and rod material properties to provide predicative capabilities. Further terminal ballistic improvements are obtained by judicious processing of the rod material in order to maximize these critical material properties.

The other ballistic performance school commits to a specific rod material and thereby concentrates on overall system requirements and designs that are compatible with the chosen rod material. The specific penetration capabilities of the chosen rod material would be enhanced by design aspects that take advantage of the most attractive properties of the material. The goal is to lessen projectile parasitic weight and thereby achieve either sufficient impact velocity or deliver higher penetrator mass to overmatch the armor target.

Evidence of a terminal ballistic performance gap between depleted uranium and tungsten is accumulating from full scale ballistic data generated at BRL. The rod materials are the standard DU-3/4 Ti alloy and a 93% W tungsten alloy (93 WA/SW) of comparable mechanical properties. The unclassified Table II-6 shows that for various rod configurations against a variety of targets, the depleted uranium consistently outperformed a tungsten rod in achieving a lower ballistic limiting velocity.

Recent full scale classified ballistic testing of advanced tungsten alloys (i.e. 93 WA(MW)) shows no closure of this performance gap. Data from these tests, in which all penetrators were machined to the 120MM M829E2 configuration, show the significant gap in limit velocities between the two materials is larger for the advanced armor tested than it was for RHA armor. Since new tungsten alloys presently undergoing development have somewhat the same basic microstructure as those tested, they are not expected to eliminate the terminal ballistic performance gap between advanced forms of these two penetrator rod materials. However, thesed new tungsten alloys, of

Table II-6 BALLISTIC PERFORMANCE - STANDARD MATERIALS

Rod Configuration — **Targets - Limiting Velocities (m/s)**

Design: Material	A	B	C	D	E
I: DU	1450	1400			
I: W	1590	1620			
II: DU			1360	1740	
II: W			1440	1750	
III: DU				1360	1590
III: W				1490	1700

themselves, may achieve a sufficiently lowered ballistic limit velocity to make them amenable to a focused system design approach capable of overmatching the projected armor threats.

These conclusions are based on the very limited amount of ballistic evaluations that have been done to date. The improved mechanical properties already demonstrated for the new tungsten alloys is encouraging and justifies continued efforts to exploit the system design options they offer. More extensive terminal ballistic testing for these newer tungsten alloys is presently underway and should shortly resolve future directions in tungsten alloy development.

b) Future Material Considerations

The tungsten alloy material studies presently maturing are not expected to result in closure of the terminal ballistic performance gap between depleted uranium and tungsten. Improvements in the critical mechanical properties for depleted uranium resulting from experimental ternary DU alloys receiving special mechanical working are expected to keep depleted uranium alloys in a commanding terminal ballistic lead. The ongoing tungsten programs, however, are expected to substantially improve the mechanical properties of these alloys above the materials produced a decade ago and thereby provide somewhat enhanced ballistic velocity limits (1-3%). However, innovative and optimized tungsten alloy/sabot assembly designs would be needed to allow these tungsten materials to re-enter the family of large caliber anti-tank rounds as strong contenders to the presently ongoing armament enhancement initiative for DU rounds.

With regard to encouraging further tungsten material efforts aimed at closure of this terminal ballistiic performance gap, a ballistic enhancement initiative effort for tungsten comparable to a similar effort on DU would be needed. Such a tungsten program would have a long term strategy and be focused mainly in the basic research and exploratory development areas. The program would incorporate recommendations of the 1989 Army Tungsten Coordination Committee (summarized in paragraph 2 below) and earlier program proposals to DARPA aimed at a leap frog approach for tungsten technology. Being long term, it will need to consider assessing tungsten against advanced ceramic and reactive armors as well as hypervelocity delivery systems.

In summary, the new tungsten alloys being developed are not expected to markedly effect the conclusions of the BRL performance analysis by the year 2000. A depleted uranium alloy rod will continue to be the mainstay for large caliber systems

from a ballistic performance standpoint. In medium caliber systems, ongoing improvements in tungsten are expected to keep this material a viable contender. Current Army and DARPA programs aimed at improving tungsten alloy penetrator performance have shown some promise, and should continue to be supported.

2. Recommended Technology Development

a. Penetrator Rod Materials

Presently, the terminal ballistic advantage lies with depleted uranium alloys, not only with respect to their superior terminal ballistic performance, but also with our being aware of the critical thermo-mechanical properties that need to be improved to sustain their superior ballistic performance. Consequently, ongoing RDT&E programs advancing DU metallurgy are expected to introduce new alloy compositions and processing for rod materials that should exhibit a 3% to 7% improvement in terminal ballistic performance over the standard DU alloy.

A similar optimistic outlook cannot be presently made for tungsten alloy development. Although major strides have been made in bringing the mechanical properties of advanced tungsten alloys up to a comparable level with DU alloys, the penetration/erosion mode for tungsten appears to be distinctly deficient so as to place it at a disadvantage with respect to DU alloys. A more fundamental look at penetrator/target interactions for tungsten is therefore necessary so as to clarify where appropriate engineering of the material can provide a beneficial ballistic failure mode to override its present terminal ballistic performance shortfall.

There are existing Army and DARPA programs aimed at improving tungsten alloy penetrator performance. The Army should continue to support such programs, since they may eventually permit the use of tungsten alloys as a viable alternative to DU for large caliber gun systems. The motivation to continue to pursue work in tungsten comes from the fact that elemental tungsten has a 1% higher density than elemental depleted uranium and thus offers the potential of becoming a formidable kinetic energy penetrator material.

If tungsten alloys were to be adjudged the only acceptable future KE penetrator material to be utilized in our arsenal of anti-armor weapon systems, a ballistic enhancement initiative for tungsten (BEIT) program would be required. Such a program would incorporate the recommendations of the 1989 Tungsten Coordination Committee in pursuing studies in the following areas:

1) Study the mechanism of penetrator failure for various armor targets.

2) Develop a process to microstructurally engineer tungsten alloys to exhibit appropriate beneficial ballistic failure modes.

3) Develop a high strain rate property data base.

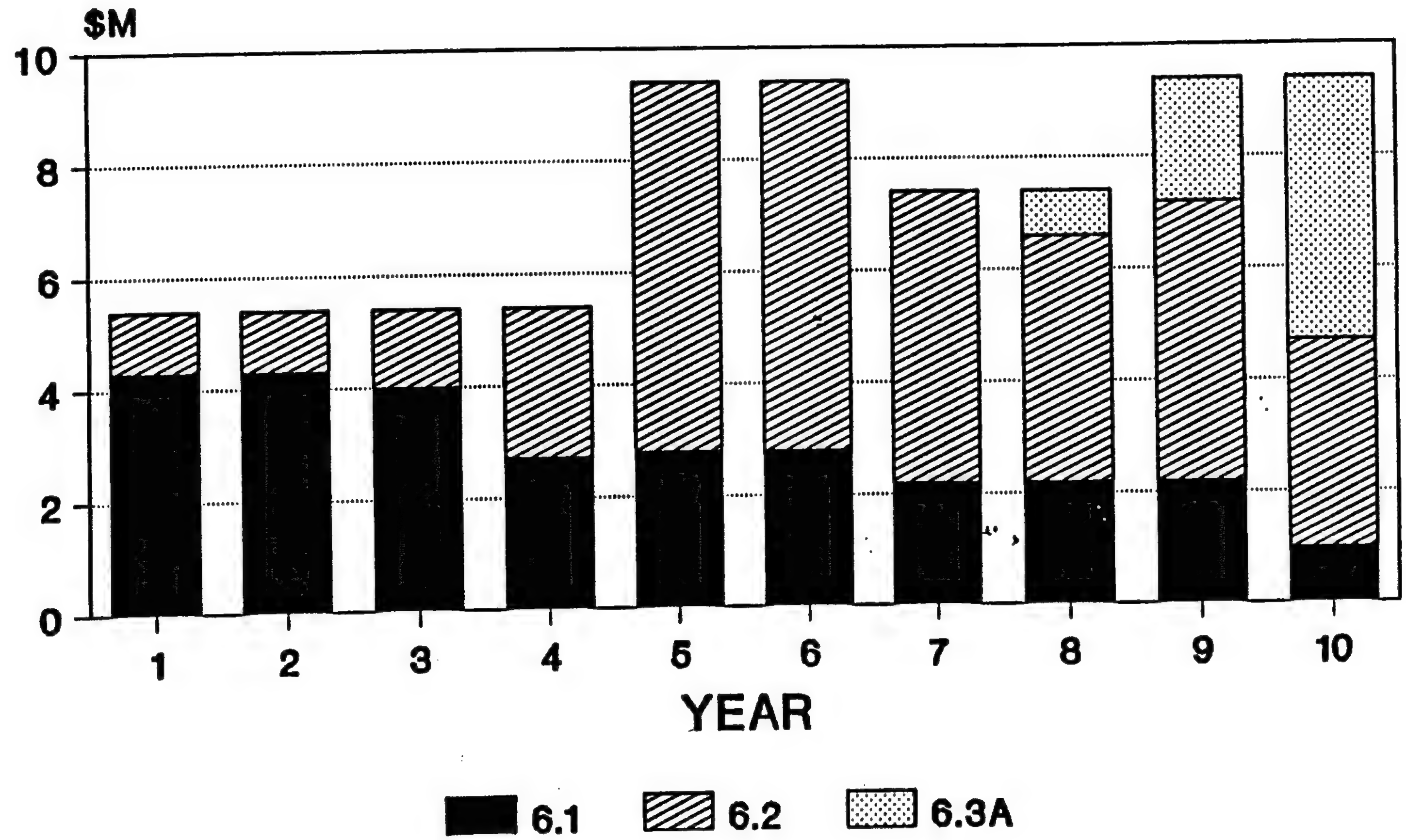
4) Develop appropriate compatible sabot material/ design for tungsten rods.

5) Develop higher density tungsten alloys.

The program envisioned would undertake several fundamental approaches aimed at elucidating what microstructural failure modes are critical during ballistic impact and penetration. Our underlying ability to develop new tungsten alloy compositions and microstructures by utilizing new processing technologies would be of paramount importance in providing the materials needed to induce these beneficial ballistic failure modes. Figure II-4 estimates the cost involved in undertaking such a broad spectrum program for tungsten.

This broad spectrum program (approximately $74M/10 years) is very comprehensive and low risk. It encompasses not only the Army's 1989 Tungsten Coordination Committee's (TCC) funding recommendation in the limited 6.1/6.2 area aimed at enhancing liquid phase sintered materials, but also considers emerging new technologies that are still in their infancy. These technologies (e.g., RST/tungsten, oriented single crystal rod) require extensive maturing since there is currently no industrial base available to produce sufficient materials via these technologies. An abridged version of this focused program ($30M/10 years) would be more high risk but would still have as its basis the recommendations of the TCC, coupled with a minimal 6.3/6.4 effort to develop promising sintered material into an ATAC cartridge.

FIG.II-4 BALLISTIC ENHANCEMENT INITIATIVE FOR TUNGSTEN



CHAPTER III

INDUSTRIAL BASE CONSIDERATIONS for the KE Penetrator Long Term Strategy Study

1. INTRODUCTION

The industrial base section of this report addresses five primary areas: penetrator quantity requirements for the years 1990-2000; material availability; material quantity requirements for the years 1990-2000; manufacturing facility requirements; and production cost comparisons. Peacetime and mobilization requirements are addressed in terms of both material quantity requirements and penetrator manufacturing facility requirements. The use of either depleted uranium or tungsten alloy has been considered. For the purposes of this study, only state-of-art processes for each material were evaluated, i.e., processes currently being employed by each industry for penetrator manufacture on a production basis. For depleted uranium, the current alloy is uranium, 3/4 percent titanium; and for tungsten alloy, a 93 percent tungsten, 7 percent iron-nickel alloy formed the basis for the study.

Material availability, capacity, quantity and facility/stockpile costs are addressed for UF_6, UF_4, uranium metal (derby) and cast metal in the case of depleted uranium and for tungsten concentrate, ammonium paratungstate (APT) and tungsten powder in the case of tungsten alloy.

The penetrator manufacturing facility cost analysis picks up where the material analysis leaves off. For depleted uranium, this means the first operation considered in the facility analysis was rolling or extrusion of rod. For tungsten alloy, the first operation in the facility analysis was blending of tungsten and alloy powders. A three shifts, eight hours per shift, five days per week (3-8-5) schedule (500 hrs per month) was used throughout this study unless otherwise noted.

For those individuals reading this report who might not be knowledgeable concerning the manufacture of penetrators, Attachment A, located at the end of this chapter, provides a brief description of the process sequences for each material.

The "Report to the Congress on National Defense Stockpile Requirements 1989" by the Secretary of Defense is referenced throughout this report with respect to stockpiling of tungsten. The methodology used in the above report with respect to mobilization (MOB) assumptions includes a one-year warning period prior to a three war year scenario. This methodology has been carried forward throughout this report. It should be noted that if the warning year is deleted, additional stockpile requirements for either depleted uranium or tungsten materials will result.

2. QUANTITY REQUIREMENTS ANALYSIS

The objective of this portion of the study was to identify the long range Government program requirements for the use of depleted uranium (DU) metal and tungsten alloy (WA) for the period of FY90 - FY2000. The major items that utilize these materials are:

- MK-149-2, 20mm (Phalanx)
- PGU-20, 25mm (GAU-12)
- M919, 25mm
- PGU-14A/B, 30mm (GAU-8)
- COMVAT
- 105/120 Tank Ammunition
  - XM900E1
  - XM872
  - M829A1
  - M829E2

- ATAC
- KEM
- ARMOR - DOD Special Billets

a. Peacetime Requirements

The office responsible for each program supplied the annual peacetime requirements data, with the exception of the Phalanx, GAU-12, and M919, which were taken from the Integrated Conventional Ammunition Procurement Plan (ICAPP) dated 15 Sep 89.

The annual peacetime requirements for each program for FY90-FY2000 are classified and are not included in this report. The quantities listed are yearly quantities for deliverable penetrators except in the case of the DOD Special Billet program which is listed in thousands of pounds deliverable DU ingot per year.

The requirements utilized represent the DOD programs that currently use depleted uranium metal or tungsten alloy and the programs that have the potential for use of these materials in the future. Of the ammunition now in production, only the

Navy 20mm Phalanx utilized WA. All other ammunition items listed utilize DU. This holds true for the DOD special billet program which utilizes scrap DU. For the purposes of this study, the M919, which is currently a DU penetrator, was also considered as a potential user of tungsten. For the future weapon systems in development (the COMVAT, ATAC and KEM systems) both DU and WA alternatives will be investigated. The material requirements for DU and WA in Shaped Charge Liner and Explosively Formed Penetrator manufacture were assumed insignificant and were not considered in the industrial base analysis. The same assumption was made for DU commercial applications. Several DOE identified program requirements were considered, but only from the point of view of whether the private sector DU manufacturers could provide material to these programs with their excess capacity.

b. <u>Mobilization Requirements</u>

Mobilization quantities represent the total DOD requirement for conventional ammunition and the Special Billet Program in the event of a national emergency or while under wartime conditions. The mobilization quantities used represent the FY90 mobilization requirements and are based on data generated from the Production Base Plan (PBP), dated November 1988. The Production Base Plan established mobilization quantities for existing ammunition. Items that are in development do not appear in the current PBP. Based on the mobilization quantities of the existing ammunition, the following assumptions were used for the long term industrial base analysis:

(1) The mobilization quantities for the GAU-8 were taken from the DOE/DOD Strategic Study of U.S. Government Depleted Uranium Requirements dated 03 Apr 89.

(2) The M919 will replace the M791 in the FY90 timeframe. The estimated mobilization quantities will be equivalent to those of the M791.

(3) The COMVAT system will replace the M919 in the FY96 timeframe. The stowed load capacity of the COMVAT system is less than that of the current M919. Based on this, a reduced mobilization requirement was used.

(4) For the current 105mm weapon system, the quantities listed are for the M833. In the FY89 timeframe the XM900E1 will replace the M833. The XM872 will subsequently replace the XM900E1. The mobilization quantities used will be the same as those of the current M833.

(5) For the current 120mm weapon system the quantities listed are for the M829. In the FY88 timeframe M829A1 replaced the M829. The M829E2 will subsequently replace the M829A1. The mobilization quantities are expected to be equal to the M829 quantities.

The mobilization quantities for the 105/120mm weapon systems appear reasonable for the immediate future. However, during the FY90 - FY2000 timeframe, the requirements for the 105mm ammunition should decrease as the 105mm tanks are phased out and the number of 120mm tanks currently available are increased proportionately. By the FY2000 timeframe, the ratio of (105mm Tanks/120mm Tanks) could be as low as 1/1. It is now approximately a 3/1 ratio. This trend is also anticipated of the future Block III Tanks expected in the late nineties timeframe. This future system would eventually replace both the 105mm and 120mm weapon systems.

3. MATERIAL AVAILABILITY

a. Tungsten Availability Considerations

(1) World Reserves

Tungsten is found and produced on nearly all continents, and ranks 26th, just behind copper, in its abundance in the earth's crust. (1) The world reserve base for tungsten by country is shown in Table III-1. (2) Approximately 80 percent of the world's estimated tungsten resources are located outside North America, with about 55 percent located in China and U.S.S.R. The reserve base is defined by the U.S. Bureau of Mines as demonstrated resources that are, or are presumed to be, technically and economically recoverable in the foreseeable future. (3) At the world mine production rate of 41,130 metric tons (MT) in 1988, the reserve base would provide tungsten for 86 years with no additions to the reserve base. The reserve base is, of course, a fluid number that can be expected to increase in the near term as new deposits are found.

(2) Concentrate Production

Tungsten minerals once removed from the earth require careful processing in order to obtain acceptable recoveries. General processing includes crushing and grinding followed by gravity and/or flotation to produce a concentrate. It is this concentrate that becomes the commodity that is marketed for further processing into tungsten products.

TABLE III-1

WORLD RESERVE BASE FOR TUNGSTEN
(MT CONTAINED TUNGSTEN)

COUNTRY	RESERVE BASE	PERCENTAGE OF TOTAL
UNITED STATES	210,000	6
AUSTRALIA	150,000	4
AUSTRIA	20,000	.5
BOLIVIA	110,000	3
BRAZIL	20,000	.5
BURMA	34,000	1
CANADA	493,000	14
FRANCE	20,000	.5
KOREA, REPUBLIC OF	77,000	2
PORTUGAL	26,000	1
THAILAND	30,000	1
OTHER MARKET ECONOMY COUNTRIES	290,000	8
CHINA	1,560,000	44
U.S.S.R.	400,000	11
OTHER CENTRALLY PLANNED ECONOMIES	105,000	3
WORLD TOTAL	3,545,000	

Figure III-1 shows the distribution of concentrate production by country for 1988. China is by far the largest producer with 49 percent. Russia is second with 21 percent of production. The United States produced only 230 MT in 1988. This production came from the only mine currently operating in North America, the Pine Creek mine in Bishop, California.

The market price for tungsten concentrate is currently at a level where most Western World mines can not afford to operate. The principal reason for the drop in Western World mine production is the low prices which result from the significant increase in tungsten concentrate imports from China. (4) This started in 1980 and has rapidly increased. Figure III-2 shows the average price per pound of contained tungsten in concentrate form since 1980.

Figure III-3 shows the distribution of tungsten concentrate consumers by country for 1988. Russia consumed 16,000 MT or 35 percent of total consumption. The United States was the second largest consumer at 7,384 MT or 16 percent of total consumption.

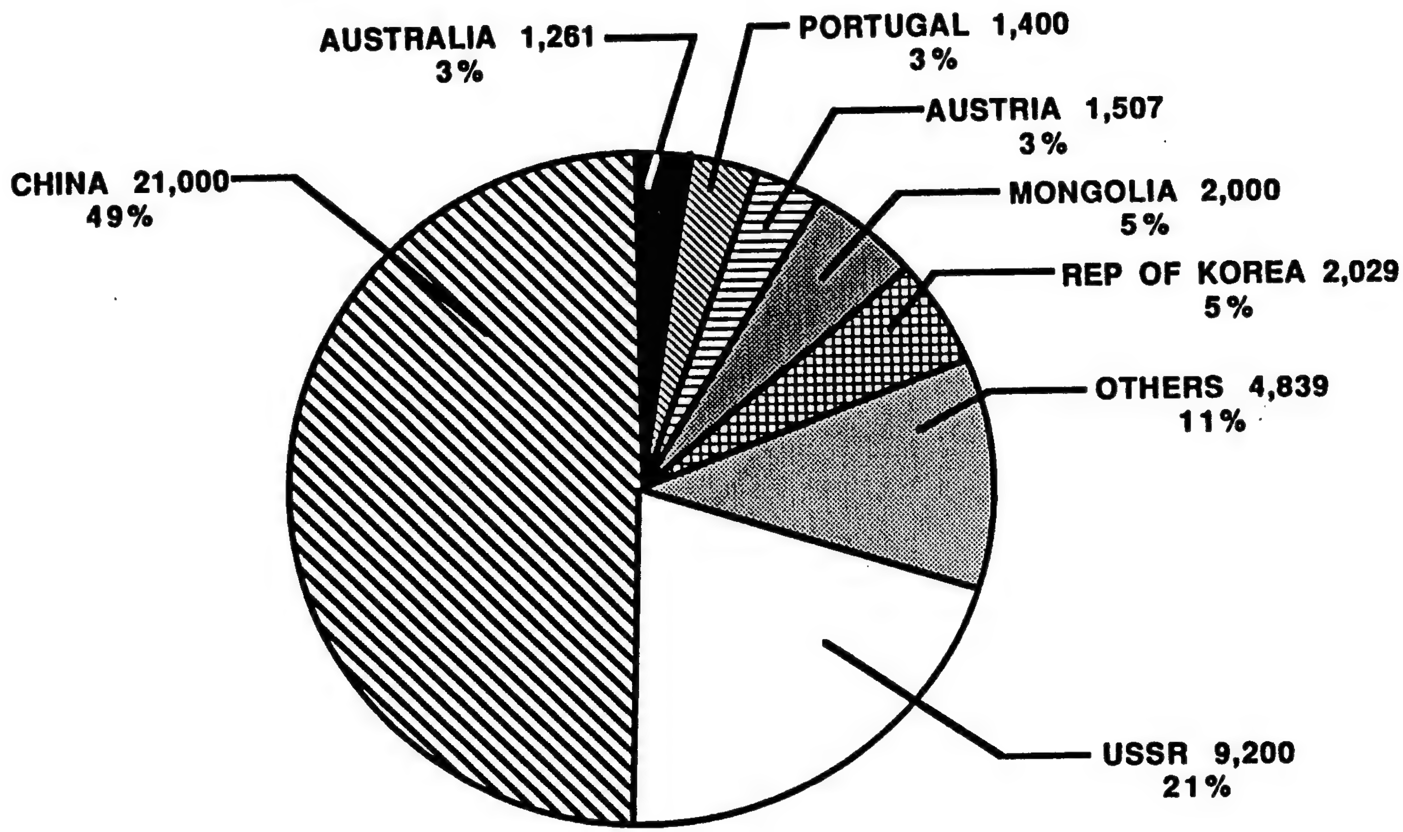
Figure III-4 shows world concentrate consumption by year since 1980. During this period of time there has been a trend toward decreased consumption. The exact reason for this decreased consumption is uncertain; however, the U.S. Bureau of Mines has made the following observations: (2)

"Advancements in carbide and oxide-coatings technology have improved the cutting and wear resistance of cemented carbide tool inserts. Coatings are estimated to be used on 30-35 percent of the inserts. The extended wear capability of the inserts decreases the replacement rate and, hence, the growth of tungsten consumption. Gradual increases in the substitution for cemented tungsten carbide base products and titanium carbide base cutting tools, by ceramic cutting tools and wear parts, and by polycrystalline diamond have also occurred. Since tungsten carbide represents the majority of tungsten consumption, at least in the United States, substitutions for tungsten carbide may in fact be the reason for reduced world tungsten consumption."

Components of U.S. concentrate supply during the period 1980 to 1988 are shown in Figure III-5. During this period the reliance on imports has increased as a percentage of yearly supply. U.S. mine shipments have decreased to less than 2 percent of supply in 1988. Shipments from the stockpile have remained a small but fairly constant source of supply during this time period. Shipments from the stockpile can be expected to decrease to zero in future years as a result of the "Report to the Congress on National Defense Stockpile Requirements 1989". (5) This report recommends that stockpile requirements for tungsten be increased from 50,666,000 lbs. to 70,900,000 lbs. The current stockpile inventory is 71,809,018 lbs. resulting in an excess of only 909,018 lbs.

Tungsten Concentrate Producers 1988

METRIC TONS, COUNTRIES >1000 MT



TOTAL PRODUCTION: 43,239 MT

095-2K

Figure III - 1

Price History Of Tungsten Concentrate

DOLLARS PER POUND OF CONTAINED TUNGSTEN

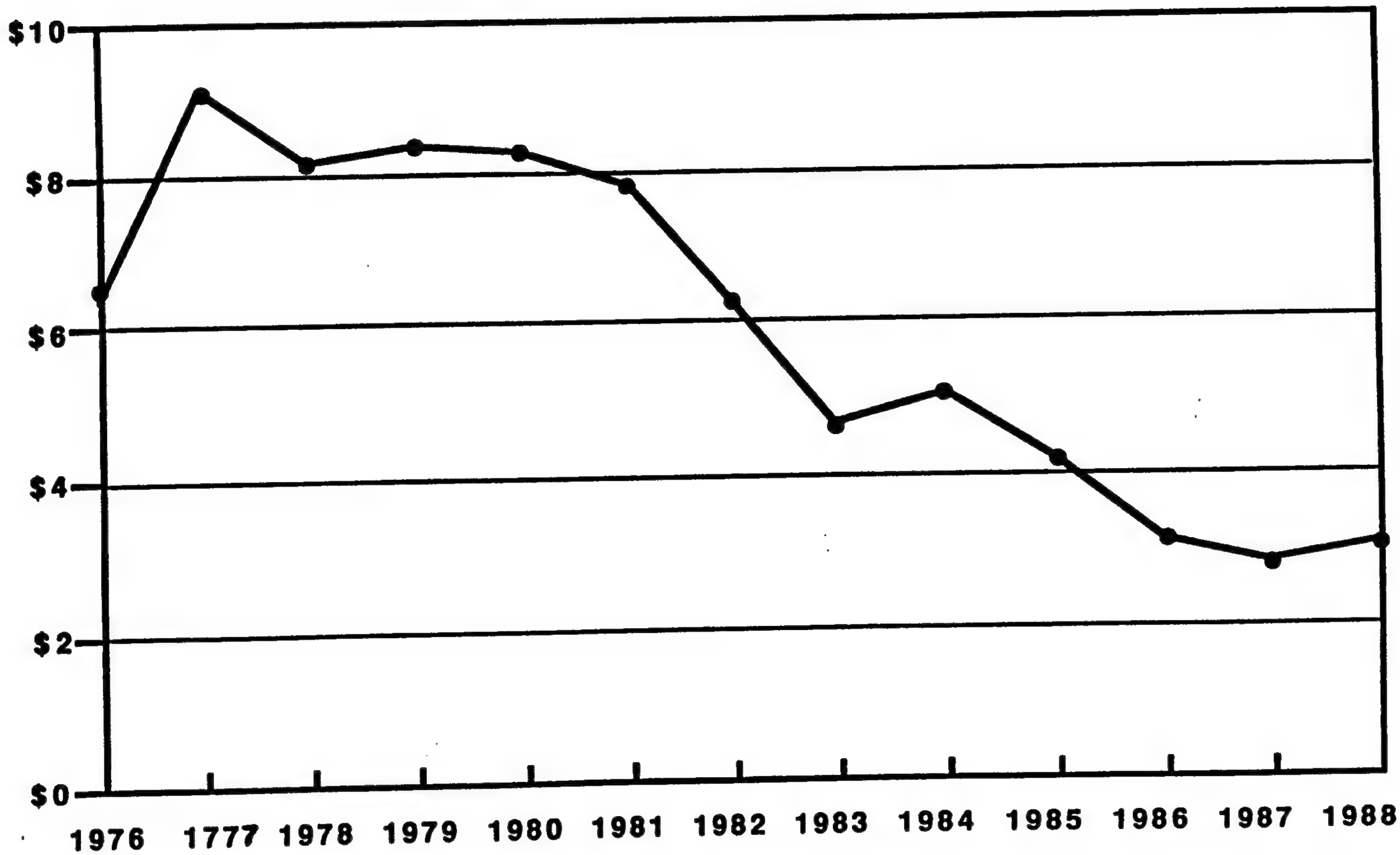
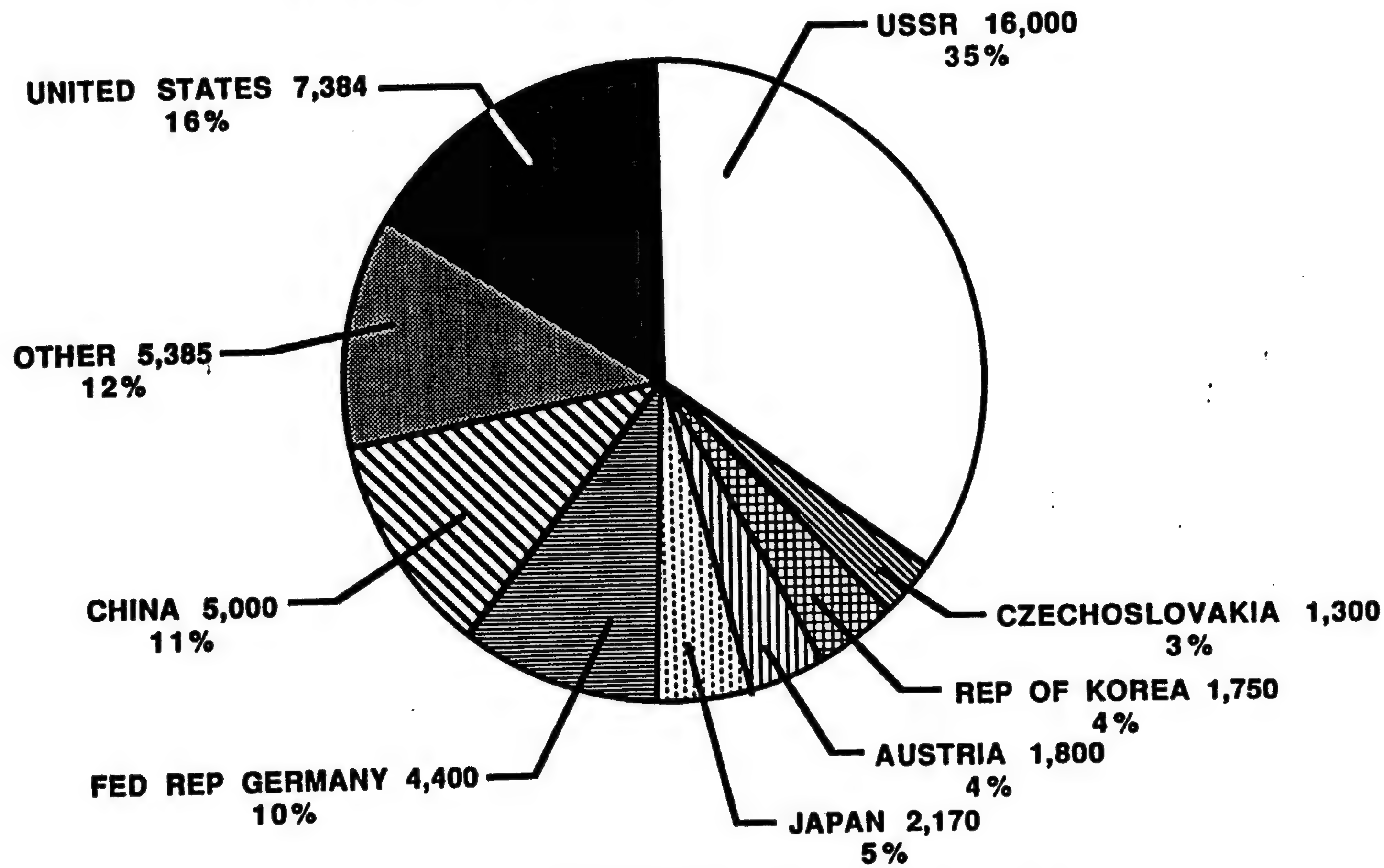


Figure III - 2

095-6K

Tungsten Concentrate Consumers 1988

METRIC TONS; COUNTRIES >1000 MT



TOTAL CONSUMPTION: 45,162 MT

095-3K

Figure III - 3

World Concentrate Production By year

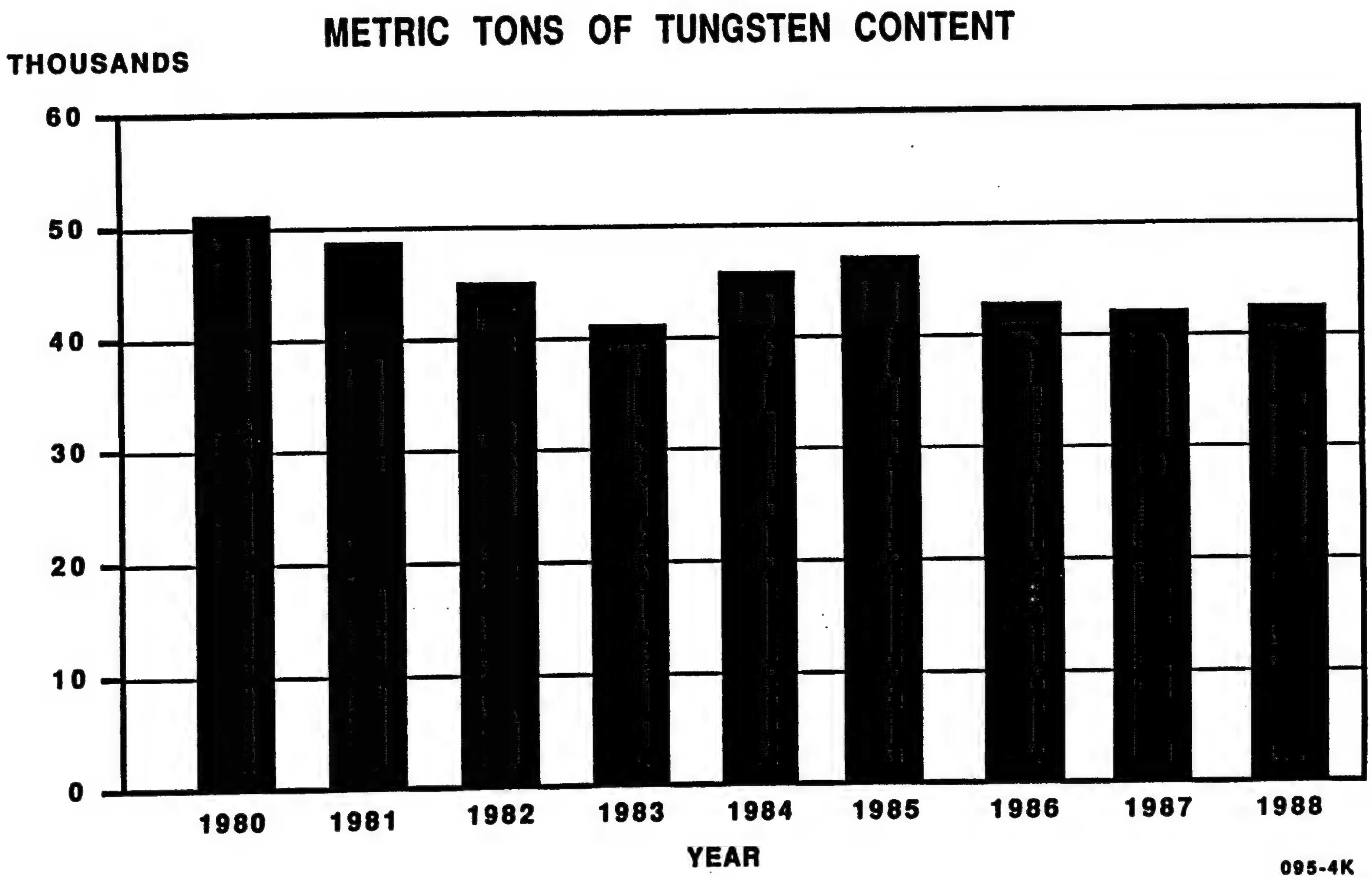


Figure III - 4

Components of U.S. Tungsten Supply 1980 to 1988

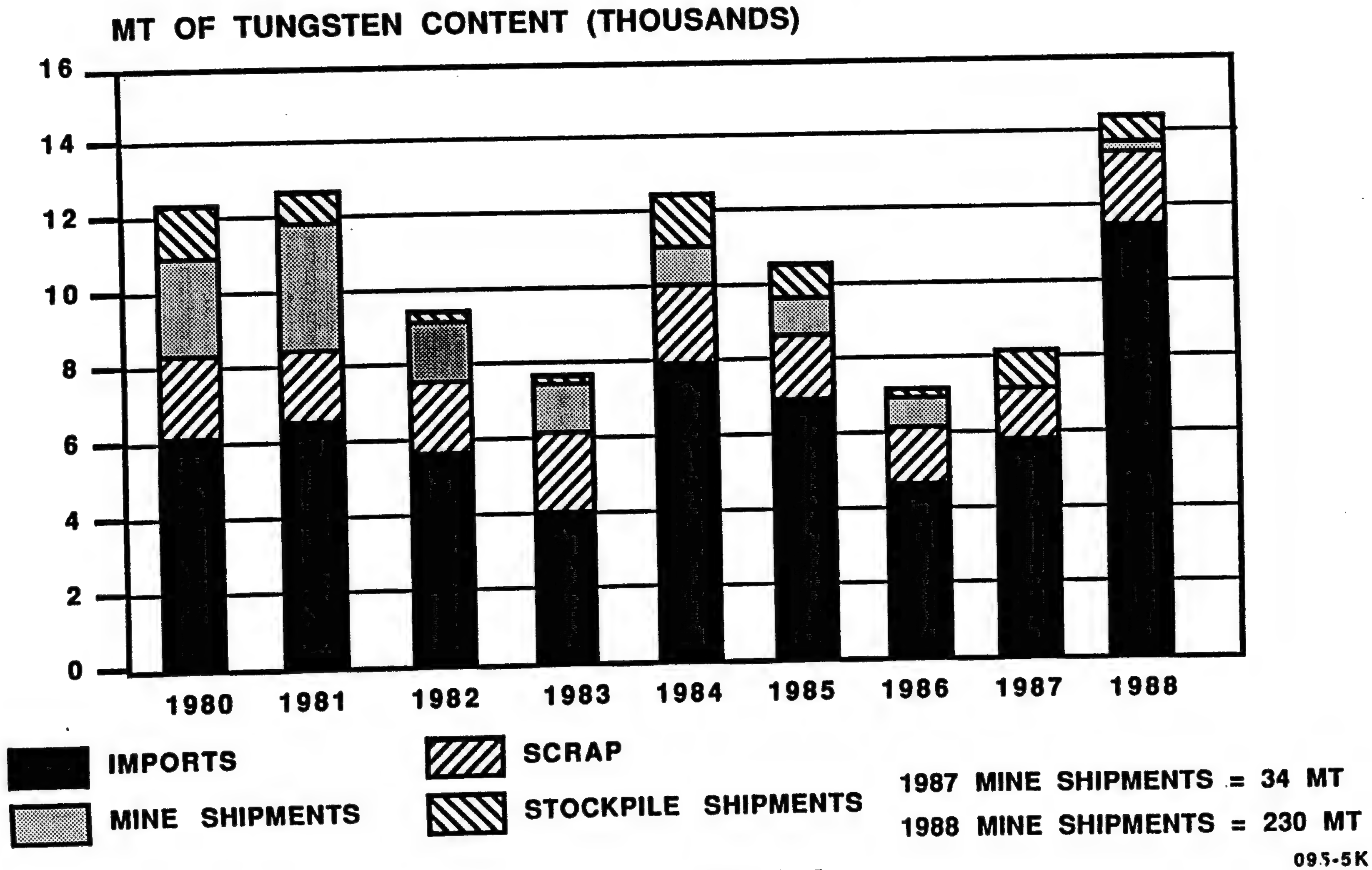


Figure III - 5

As shown in Figure III-5, the use of scrap represents a significant percentage of total concentrate consumption which has the benefit of conserving natural resources. Currently the main source of scrap is carbide cutting tools; however, the recycle percentage is quite low. In the event of mobilization, usage of cutting tools would increase significantly. At that time a requirement for recycling could be imposed which could go a long way in satisfying tungsten concentrate demand. The Refractory Metals Association has estimated that if the situation warranted it, scrap could supply 50-60% of the feed into an APT plant. It should be noted that all scrap generated in production of penetrators could and would be recycled.

(3) Peacetime Outlook for Supply of Concentrate

The only potential problem that can be foreseen in the supply of tungsten concentrate for peacetime usage is the current heavy reliance on imports from China. In 1988 approximately 50 percent of U.S. tungsten concentrate imports came from China. Barring any cutbacks in imports from China, the increased demand that would result from making all U.S. penetrators from tungsten could be expected to be met by increased imports. Cutbacks on imports from China could result in short term shortages until other sources of supply come into being. Any such short term shortages would have to be met by releases from the stockpile.

(4) Mobilization Outlook for Supply of Concentrate

The mobilization picture for supply of concentrate is a much more difficult issue to address. In a mobilization scenario the supply of imports can be expected to be severely restricted, particularly when one considers that over 50 percent of U.S. imports come from mainland China. This restriction on imports makes it necessary to consider the U.S. mine capacity for production of concentrate in an emergency situation. Fortunately the U.S. Bureau of Mines has made such an assessment which was used in establishing stockpile requirements for tungsten, contained in the "Report to the Congress on National Defense Stockpile Requirements 1989". (5) Likewise, the State Department has done a risk assessment concerning imports, and they have estimated the import quantities that could be expected during a mobilization period. These estimates are also contained in the above report. Table III-2 provides a tabulation of all tungsten concentrate sources and estimated quantities that could be obtained during the mobilization period. The Institute for Defense Analysis (IDA), who do the modeling studies used to establish stockpile requirements, was asked to assess the tungsten requirements for ammunition that went into establishment of current military tungsten stockpile requirements. What they found was that out of an ammunition requirement totaling $63 billion during the four year planning period, there was only

TABLE III-2

TUNGSTEN CONCENTRATE SOURCES DURING MOBILIZATION PERIOD
(MT TUNGSTEN CONTENT)

	WARNING YEAR	WAR YEAR 1	WAR YEAR 2	WAR YEAR 3
U.S. CURRENT FACILITIES (1)	2,721	2,993	3,719	4,082
RE-OPENED U.S. FACILITIES (2)	2,540	3,991	4,127	4,172
IMPORTS (3)	4,263	4,036	4,308	4,626
STOCKPILE (3)	—	10,855	10,855	10,855
TOTAL	9,524	21,855	23,009	23,735

(1) ONE U.S. MINE PLUS RECYCLE MATERIAL PER U.S. BUREAU OF MINES ESTIMATE.

(2) U.S. BUREAU OF MINES ESTIMATE.

(3) SOURCE: "REPORT TO CONGRESS ON MATERIAL DEFENSE STOCKPILE REQUIREMENTS 1989".

14,000 lbs. of tungsten in the stockpile allocated to ammunition. Obviously current input to their model does not include a requirement for tungsten penetrators. The obvious question is, "Would any of the stockpile be available for penetrators?" The answer is that a priority system would be established for use of the stockpile. The next question is, "What would have a higher priority, penetrators or tungsten carbide cutting tools needed to machine all the war materials required to be manufactured?" This is not any easy question to answer. The conservative approach to answering this question would be to increase the stockpile by the amount required to meet penetrator mobilization quantities.

The above discussion points up one area of concern that will have to be addressed if penetrator production is shifted from depleted uranium (DU) to tungsten (W).

(5) <u>Ammonium Paratungstate (APT) Capacity</u>

Ammonium paratungstate, which is manufactured from tungsten concentrate or tungsten scrap, is an intermediate product from which tungsten powder is manufactured. United States APT capacity is 13,425 MT per year. APT for U.S. consumption is provided, for the most part, by United States APT producers as shown in Figure III-6. (6) Imported APT represents only a small percentage of United States APT consumption. On May 22, 1987, the United States International Trade Commission ruled that imports of APT and tungstic acid from China had caused injury to the U.S. tungsten industry. On September 28, 1987 an agreement was signed between the U.S and China limiting imports of APT and tungstic acid as follows: last quarter 1987, 193 MT of tungsten content: 1988, 821 MT; 1989, 880 MT; 1990, 930 MT; and the first nine months 1991, 680 MT.

The consumption of APT in any given year varies rather widely so it is not possible to project excess capacity with a high degree of accuracy. The average consumption during the 1980-1988 time period was 7,414 MT, and in 1981 the maximum consumption of 9,165 MT occurred. Based on these numbers excess capacity during peacetime is estimated at between 4,300 and 6,000 MT tungsten content. For this study excess capacity of 4,300 MT will be used. Under mobilization conditions, and without use of tungsten for penetrators, it can be expected that there would not be any excess APT capacity. This assessment is based on estimated tungsten usage during mobilization as contained in the "Report to Congress on Material Defense Stockpile Requirements 1989". (5)

(6) <u>Tungsten Powder Capacity</u>

Tungsten powder is the starting material which, when blended with appropriate alloying powders, is used to fabricate tungsten alloy (WA) penetrators. Nearly all tungsten powder for

United States APT Supply 1980 - 1988

MT OF TUNGSTEN CONTENT

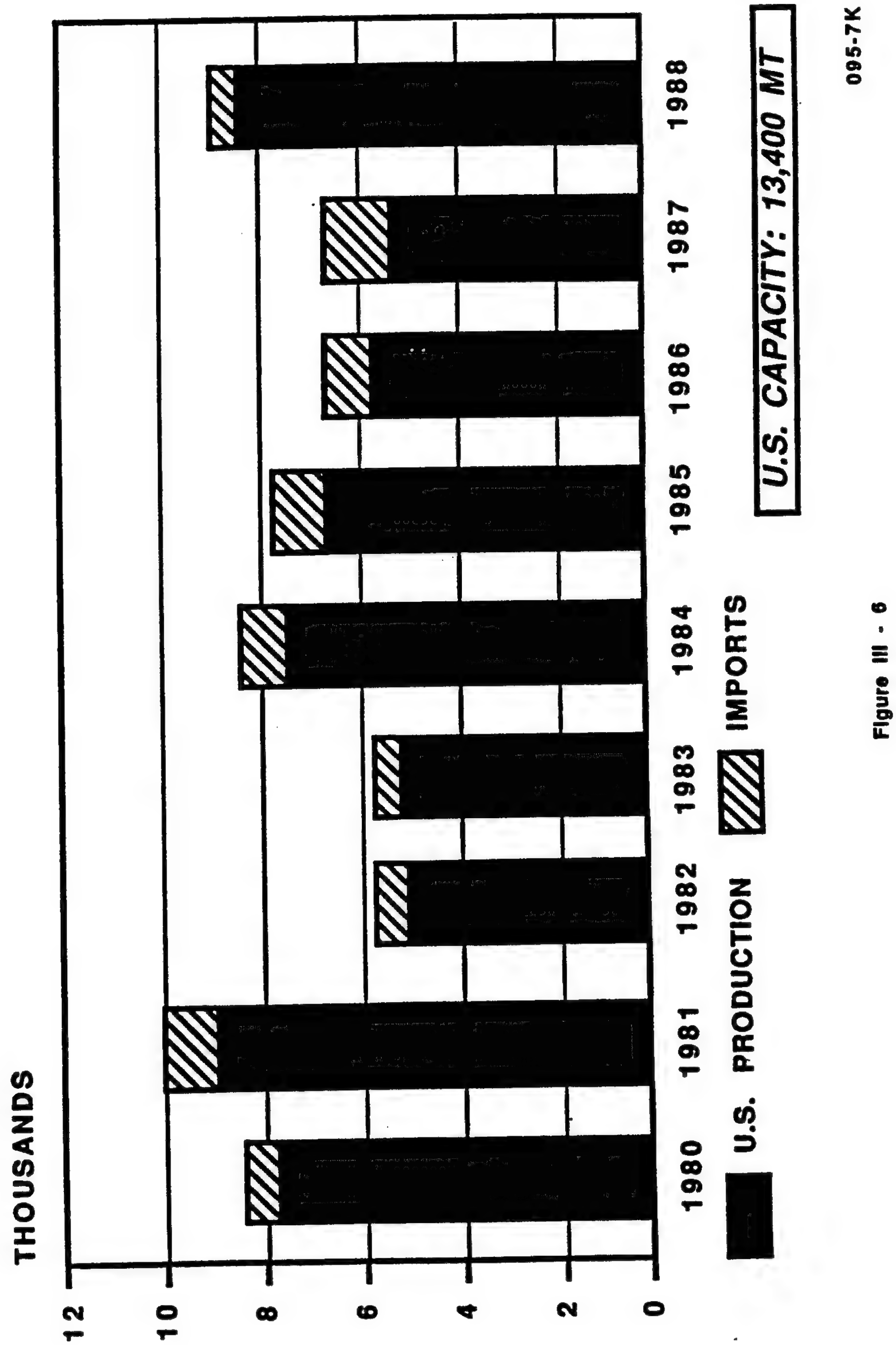


Figure III - 6

U.S. consumption is produced in the United States. United States tungsten powder capacity is 13,786 MT per year. This capacity is nearly equal to the 13,425 MT of contained tungsten APT capacity which is logical since APT is the intermediate product for conversion of tungsten concentrate to tungsten powder.

United States tungsten powder production for the years 1980-1988 is shown in Figure III-7. (6) Like APT production, the production of tungsten powder varies from year to year so it is not possible to estimate excess capacity precisely. The average consumption during the 1980-1988 time period was 7,232 MT and in 1981 the maximum consumption of 8,959 MT occurred. Based on these numbers excess capacity during peacetime is estimated at between 4,827 and 6,554 MT tungsten content. For this study excess peacetime capacity of 4,800 MT will be used. Under mobilization conditions, even without use of tungsten for penetrators, it can be expected that there would not be any excess tungsten powder capacity. This assessment is based on estimated tungsten usage during mobilization as contained in the "Report to Congress on National Defense Stockpile Requirements 1989". (5)

(b) Depleted Uranium Availability Considerations

(1) UF_6 SUPPLY

The DOE recently completed a study on U.S. Government depleted uranium requirements. Their draft report, dated April 3, 1989, is titled "Strategic Study of U.S. Government Depleted Uranium Requirements" (7). This report shows that excluding the mobilization requirement, planned annual production of depleted UF_6 is greater than consumption. The existing inventory plus planned production will, however, supply all requirements including the mobilization requirements for the entire planning period.

(2) UF_4 Derby and Cast Metal Capacity

Table III-3 shows the U.S. capacity for production of UF_4, derby and cast metal. Uranium fluoride (UF_4) is an intermediate product in the production of uranium metal which is made from UF_6. UF_4 is often referred to as "greensalt". UF_4 is mixed with magnesium chips and heated to cause a thermic reaction which results in the formation of magnesium fluoride and molten uranium metal which settles to the bottom of the reaction vessel and solidifies in the form of a derby. The derby is then melted along with scrap and alloy additions and cast into ingots or billets.

U.S. Tungsten Powder Production

MT OF TUNGSTEN CONTENT

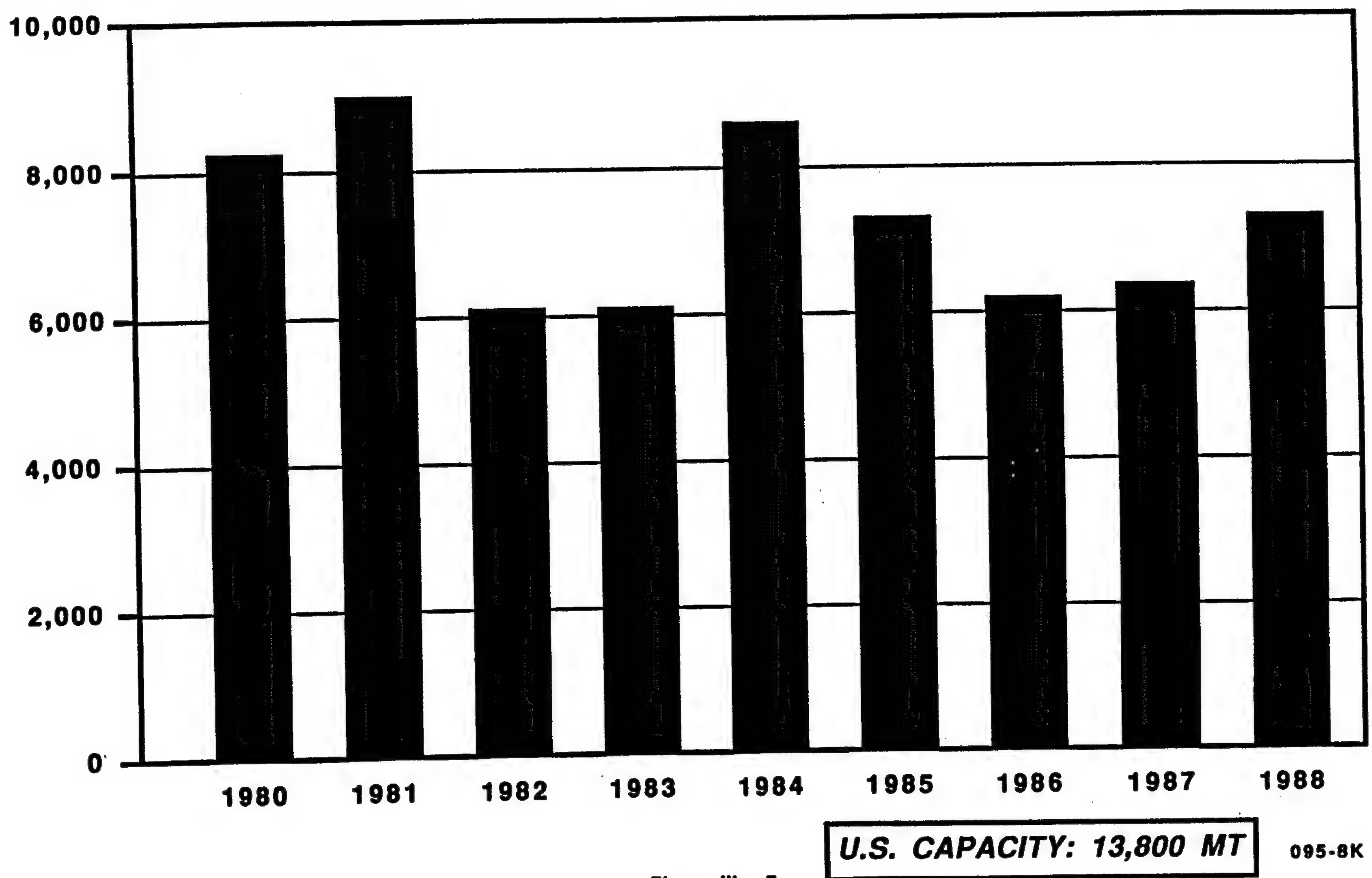


Figure III - 7

Table III-3

YEARLY NORTH AMERICAN PRODUCTION CAPACITIES FOR DEPLETED URANIUM (UF_4, Derby & Casting)

(MT Contained Uranium)

Source	UF_4	Derby	Casting
U.S. Private Sector			
NMI	YES (CMI)	YES (CMI)	YES
Sequoyah Fuels	YES	NO	NO
Aerojet	NO	YES	YES
Manufacturing Sciences Corp.	NO	NO	YES
Total	3,923	6,534	9,800
DOE			
FMPC	YES	YES	YES
Y-12	NO	NO	YES
Canada			
Eldorado	NO	YES	YES
Grand Total	6,683	15,018	20,402

Information on each producer is presented below:

(a) Sequoyah Fuel

Sequoyah Fuel, located in Gore, Oklahoma, has a facility for reduction of UF_6 to UF_4.

(b) Nuclear Metals Inc. (NMI)

NMI, located in Concord, Massachusetts, is the only U.S. commercial uranium supplier with a wholly owned captive facility for converting UF_6 to final metallic uranium form. NMIs' facility, Carolina Metals Inc. (CMI), located in Barnwell, South Carolina, was built in the 1984-85 time frame.

(c) Aerojet Ordnance Tennessee (AOT)

Aerojet Ordnance Tennessee, in Jonesborough, Tennessee, has facilities for converting depleted UF_4 to uranium metal forms. Aerojet is the other U.S. producer of depleted uranium penetrators.

(d) Manufacturing Sciences Corp. (MSC)

Manufacturing Sciences Corp., in Oak Ridge, TN has recently installed a cast metal capability.

(e) Feed Materials Production Center (FMPC)

The FMPC is operated under the direction of DOE-ORO and the DOE-FMPC Site Office. The reduction in projected production levels, especially of those products produced in the DOE facilities, has prompted various studies on the feasibility of transferring production responsibility from DOE to the commercial sector.

(f) Y-12

Y-12 located at Oak Ridge, Tennessee is operated under the direction of DOE-ORO and has facilities for metal casting. The required feed material for Y-12 is derby or scrap uranium materials. (7)

(g) Eldorado

A plant is operated by Eldorado Nuclear Ltd. in Port Hope, Ontario, Canada, which starts with UF_4 and produces uranium metal forms. The required starting feed material at this plant is UF_4.

4. STARTING MATERIAL QUANTITY REQUIREMENTS

a. Peacetime Quantity Requirements

For the purpose of this study, starting material is tungsten concentrate for tungsten and UF_4 for depleted uranium respectively. In addition to starting material, there are subsequent processing operations that should be considered when evaluating material requirements. For depleted uranium, these additional operations are manufacture of derby and casting of ingot. For tungsten, the additional operations are manufacture of APT and tungsten powder. Quantities of all materials will be referred to in terms of metric tons of contained tungsten or metric tons of contained uranium.

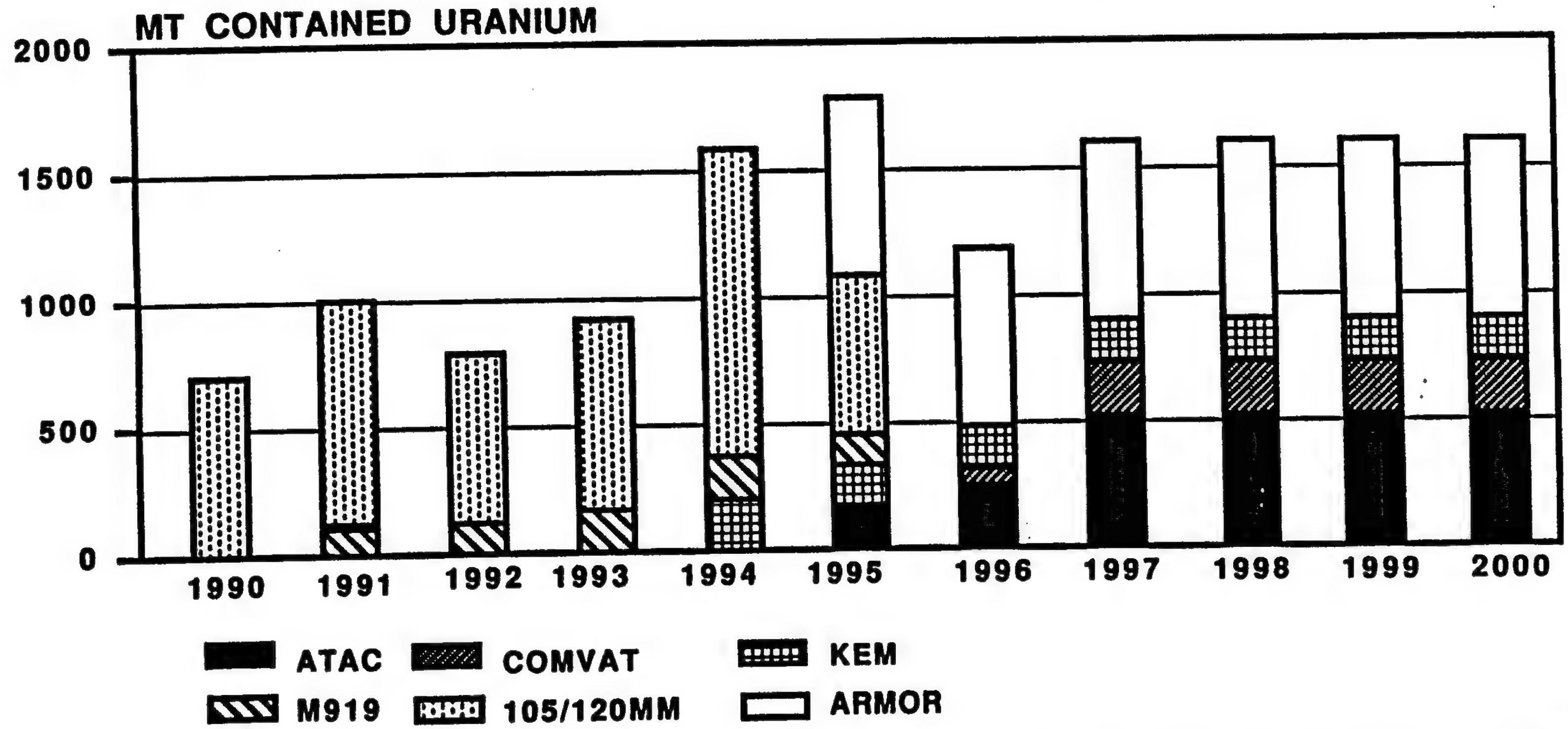
Peacetime yearly quantity requirements of UF_4, derby and cast depleted uranium for the period 1990 to 2000 for all of the items included in this study as being either definite or potential users of DU are shown in Figure III-8 (UF_4 and derby) and Figure III-9 (casting). Quantity requirements of UF_4 and derby are the same in terms of contained uranium and are thus shown together in Figure III-8. The data in Figure III-8 and III-9 show that the U.S. private sector UF_4, derby and casting capacity is adequate to meet peacetime requirements if all of these items were made from depleted uranium. The armor requirement is zeroed out until 1995 as current planning is to use available inventory plus scrap until 1995 at which time it will be consumed. Even without use of scrap inventory for the armor program, private sector capacity is adequate for all peacetime requirements.

Depleted uranium DOD penetrator material requirements for the years FY86 thru FY89 are presented below which, when compared with projected requirements in Figure III-8, show the significant decrease in requirements which started in FY88.

Year	DOD Requirement
FY86	1,688 MT
FY87	1,723 MT
FY88	1,006 MT
FY89	730 MT

In FY86-FY88 Army requirements were supplemented by at least 360 MT of requirements from Navy and Air Force. FY89 is a transition year with approximately 225 MT of Navy requirements in addition to the Army requirements. The Navy Phalanx System has recently been converted from DU to WA for the penetrator; hence, in FY90 and beyond, there are no substantial requirements beyond those of the Army.

Yearly Peacetime Requirements Of UF4 And Derby By Item

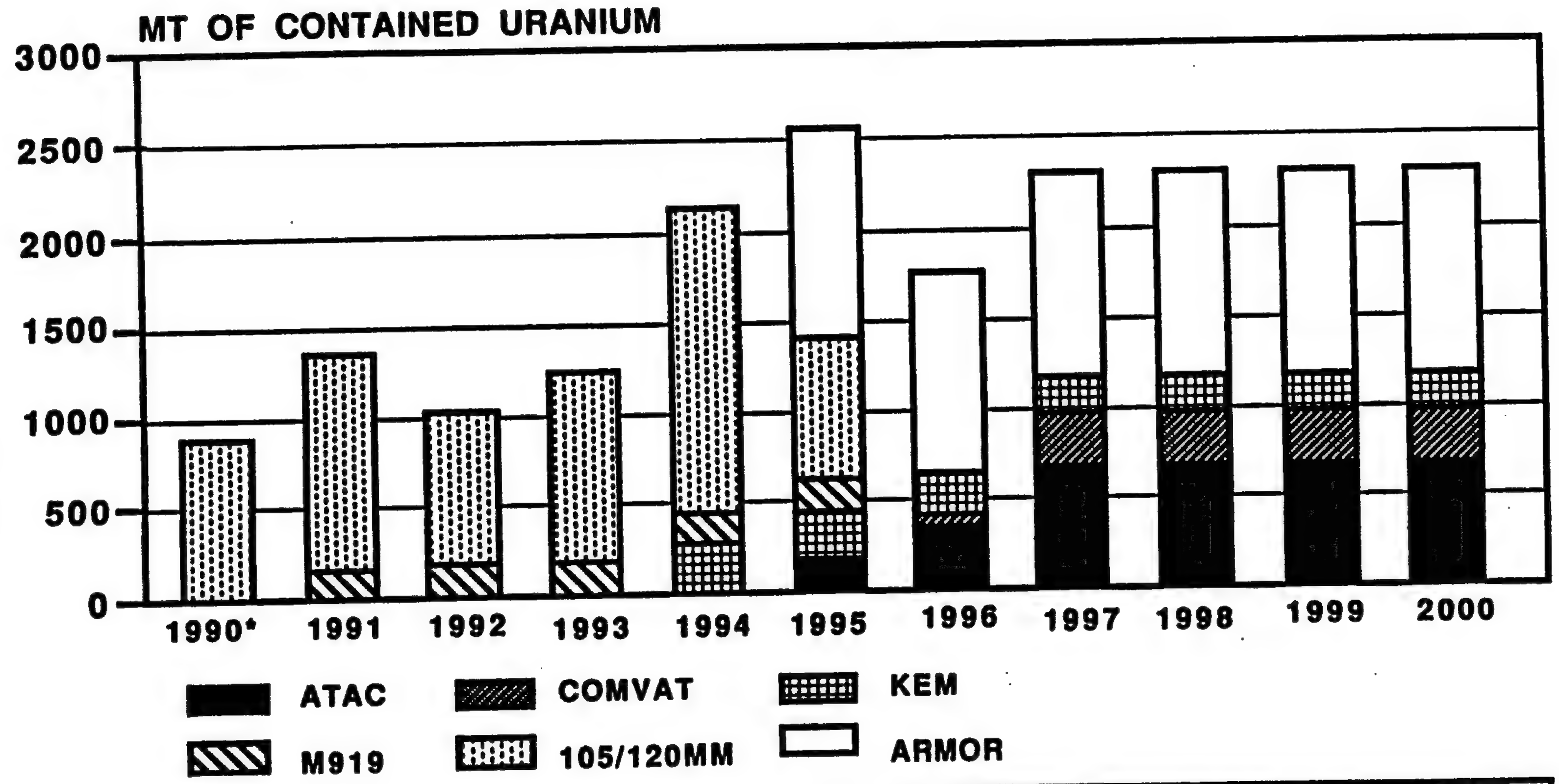


PRIVATE SECTOR UF4 CAPACITY: 3923 MT
PRIVATE SECTOR DERBY CAPACITY: 6534 MT
GAU 12 REQUIREMENT (1992-2000): 4 MT/YR

095-13K

Figure III - 8

Yearly Peacetime Requirements Of Cast DU By Item



U.S. PRIVATE SECTOR CAPACITY: 7600 MT
* M919 1990 REQUIREMENT: 18 MT

095-12K

Figure III - 9

Peacetime yearly quantity requirements of tungsten concentrate and tungsten powder for the period 1990 to 2000 for all of the items included in this study as being either definite or potential users of tungsten are shown in Figure III-10 (concentrate) and Figure III-11 (APT & powder). Quantity requirements of APT and tungsten powder are nearly equal in terms of contained tungsten and are thus shown together in Figure III-11. There is approximately a 3 percent processing loss in going from APT to tungsten powder so the APT quantity will be larger than the tungsten powder quantity by this factor. The maximum yearly tungsten concentrate requirement is 736 MT contained tungsten. This represents only a 10 percent increase in U.S. 1988 tungsten concentrate consumption. No problem is anticipated in being able to import this additional quantity of tungsten during peacetime barring any cutbacks in imports from China. The excess APT and tungsten powder capacity is also adequate to meet peacetime demands for penetrators.

b. MOB Material Quantity Requirements

Mobilization material quantity requirements for all of the penetrators and armor items considered in this study as being either definite or potential users of DU or tungsten are shown in Table III-4. The first question that will arise in reviewing Table III-4 is, "Why is the tungsten concentrate quantity always lower for a specific item than the UF_4 requirement?" There are two primary reasons for the difference noted. First, for the purposes of this study, a 93 percent tungsten alloy was assumed; thus, the tungsten weight will always be lower than the uranium weight per penetrator. Secondly, all tungsten scrap generated in manufacture of a tungsten penetrator can be recycled whereas for DU most of the machining chips are not currently recycled. In the case of the tungsten ATAC penetrator, this recycle represents 50 percent of the weight of the starting blank considering both process losses and machining chips. Use of recycle reduces starting concentrate requirements accordingly.

Another question that may arise is, "Why is the quantity of cast DU ingot always higher than the APT/W powder quantity for any given item?" Again, because of the 93 percent tungsten alloy, the tungsten quantity will always be lower. In addition, there are scrap losses in extrusion or rolling, and in cutting of blanks in the DU processing, which cause the cast ingot quantity requirements to be higher. Lastly there is the question of why cast ingot requirements are higher than UF_4/derby requirements. There is a certain percentage of scrap which is recycled into the casting operation; thus, the amount of cast ingot always exceeds UF_4 and derby requirements.

Yearly Peacetime Requirements Of Tungsten Concentrate By Item

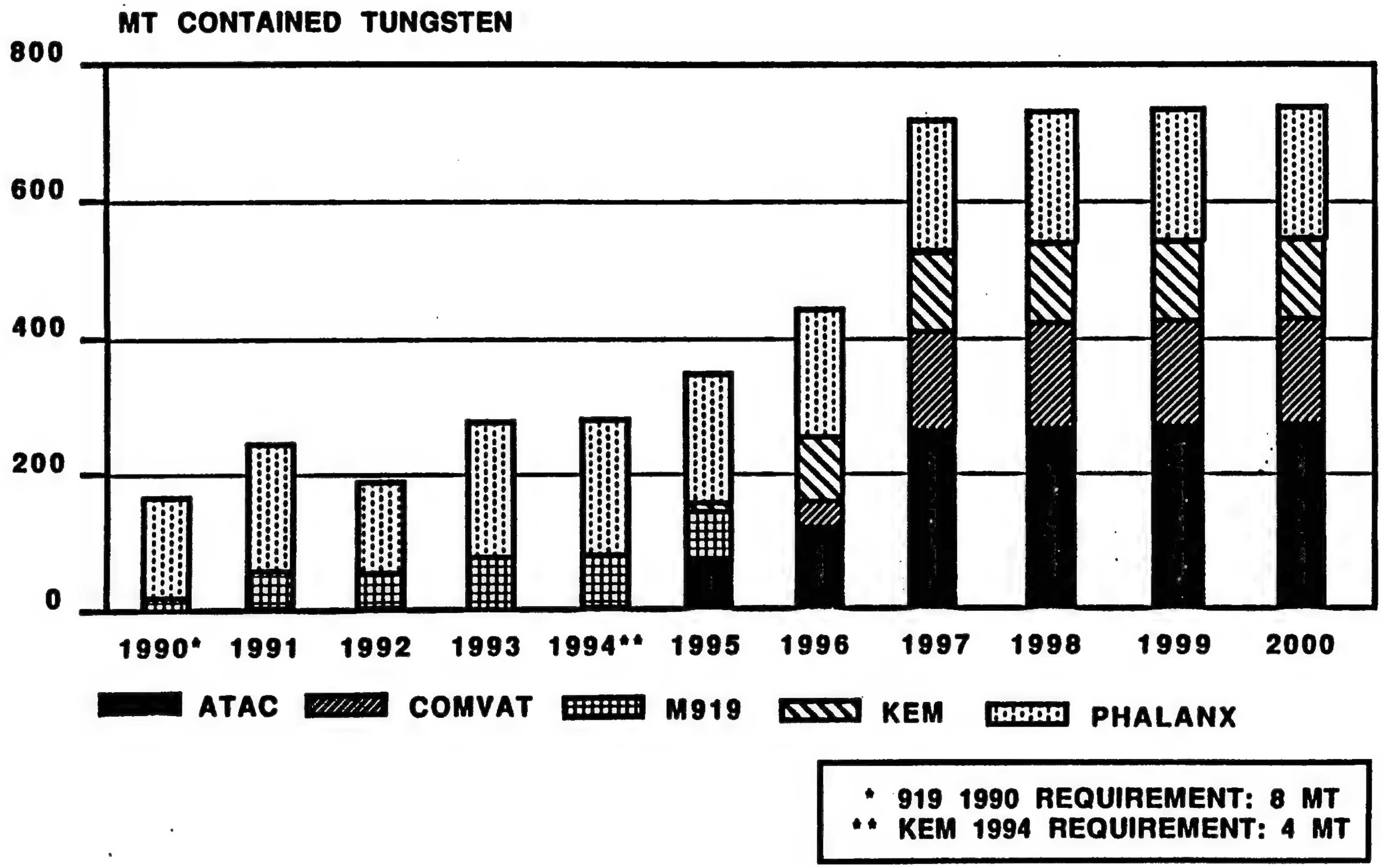
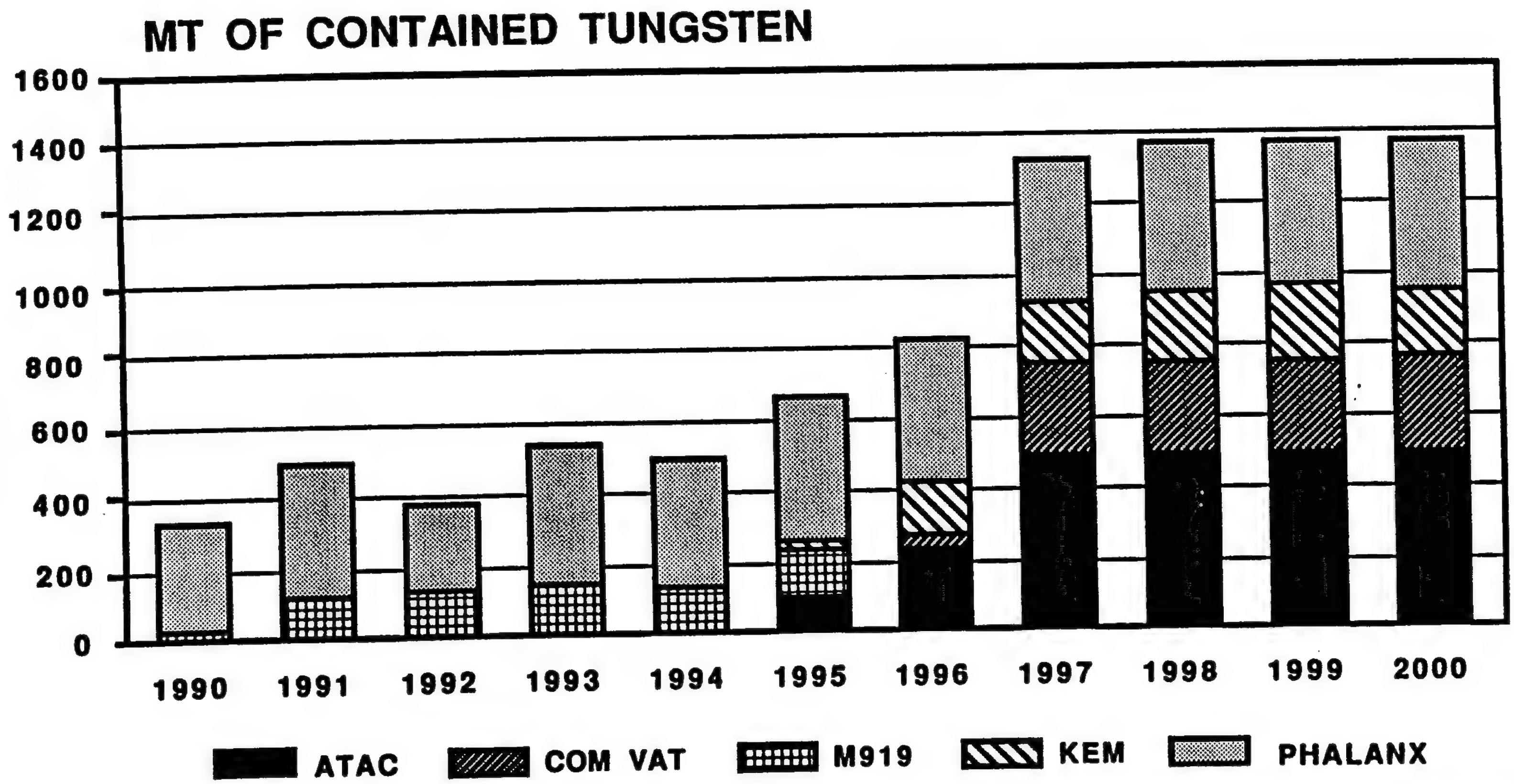


Figure III - 10

095-11K

Yearly Peacetime Requirements Of APT/Tungsten Powder By Item



PRIVATE SECTOR CAPACITY
APT: 4300 MT
POWDER: 4800 MT

Figure III - 11

095-9K

TABLE III-4

YEARLY MOB MATERIAL QUANTITY REQUIREMENTS BY ITEM
(MT CONTAINED URANIUM OR TUNGSTEN)

ITEM	UF_4/DERBY	CAST INGOT	TUNGSTEN CONCENTRATE	APT/W POWDER
ATAC	1,409	1,921	779	1,567
COMVAT	340	463	232	403
KEM	561	693	401	644
919	322	416	180	363
105	3,291	4,451	-----	-----
ARMOR	1,855	2,854	-----	-----
GAU-12	126	178	-----	-----
GAU-8	8,163	11,533	-----	-----
PHALANX	------	------	488	1,032
TOTAL	15,745*	22,093*	1,900*	3,646*

* 919 QUANTITY NOT INCLUDED IN TOTAL. COMVAT REPLACES 919 AND COMVAT QUANTITY IS LARGER, THEREFORE, COMVAT QUANTITY USED.

Table III-5 summarizes the peacetime and MOB quantity requirements and U.S. private sector capacity for UF_4, derby and casting in the case of depleted uranium and concentrate; APT and powder in the case of tungsten. This table shows that private sector capacity is adequate to meet all peacetime starting material and material processing requirements for both depleted uranium and tungsten. Shortfalls exist in MOB capacity for UF_4, derby and casting even if DOE and Canadian capacity is included. One item that should be considered is the large MOB requirement for GAU-8. Is this a realistic requirement? If this requirement could be significantly reduced, it would go a long way toward either eliminating or reducing the capacity shortfalls that currently exist. In the case of tungsten, shortfalls in capacity can be expected under MOB as the stockpile does not currently include concentrate for penetrator application. Based on projected wartime requirements for tungsten, APT and tungsten powder capacity would be 100 percent utilized for domestic and military wartime requirements that currently do not include requirements for penetrators. It should be noted that there are no Canadian facilities for manufacture of APT or tungsten powder.

c. <u>Stockpile/Facility Costs for MOB Material</u>

Costs to either stockpile or facilitize for the MOB material shortfall for depleted uranium and tungsten are shown in Table III-6. Costs to stockpile represent estimates based on current prices for the various uranium and tungsten forms shown in Table III-6. The estimate for costs to facilitize come from various sources. The cost of equipment for depleted uranium facilities was obtained from the two current penetrator producers. With respect to tungsten concentrate, the U.S. Bureau of Mines has estimated that to open new U.S. tungsten mines with an annual capacity of 10,000 MT would cost $469 million. (5) The APT facility cost estimate was provided by the Refractory Metals Association. (8) The tungsten powder furnace equipment estimate was obtained from tungsten industry sources visited during this study.

In reviewing the costs in Table III-6, with one exception it is noted that it is always cheaper to facilitize for an annual MT of material than it is to stockpile a MT of material. The one exception is the cost to open mines for tungsten concentrate. The exorbitant costs to open new U.S. mines show that it is far less costly to store the required 3 war year quantity in the stockpile than it would be to open U.S. mines. The 30 months lead time to open mines also would not provide the required material on a timely basis if one were to wait until the warning year of a mobilization period to initiate this action.

Table III-5

PEACETIME & MOB YEARLY QUANTITY REQUIREMENTS & U.S. PRIVATE SECTOR CAPACITY

(MT Contained Uranium or Tungsten)

Material Processing Step	Maximum Yearly Requirement Peacetime	Maximum Yearly Requirement MOB	Peacetime U.S. Private Sector Capacity	North American Capacity (1)
Depleted Uranium				
UF_4	1,795	15,745	3,923	6,683
Derby	1,795	15,745	6,534	15,018
Casting	2,536	22,093	9,800	20,402
				(Excess Capacity) (2)
Tungsten				
Concentrate	736	1,900	Use Imports	None (3)
APT	1,402	3,646	4,300	None (3)
Powder	1,360	3,537	4,800	None (3)

(1) North American capacity includes DOE and Canadian facilities.

(2) Excess capacity is that capacity which would be available for penetrators considering maximum utilization of existing total capacity over last nine years.

(3) All current capacity needed to meet Military and domestic MOB requirements other than penetrator.

TABLE III-6
STOCKPILE/FACILITY COSTS FOR MOB MATERIAL

MATERIAL	COST TO STOCKPILE ($ PER MT)	COST TO FACILITIZE ($ PER ANNUAL MT CAPACITY)	TIME TO FACILITIZE (MONTHS)
DEPLETED URANIUM			
UF_4	4,630	1,340	12
DERBY	11,025	430	12
CAST INGOT	16,537	500	12
TUNGSTEN			
W CONCENTRATE	7,629	47,000	30
APT	11,245	3,500	24
TUNGSTEN POWDER	22,049	900	12

Keeping in mind that MOB facilities may never be needed, the most cost effective approach to the MOB material quantity problem appears to be to use the warning year of a mobilization period to build the required facilities with the exception of tungsten concentrate, which should be stockpiled as soon as possible. A more precise answer to this question would require a detailed economic analysis wherein various scenarioes concerning the length of time to MOB would be considered. It would not be advisable to wait until the warning year to stockpile W concentrate as the source for imports might not be available at that time. Using this approach, all depleted uranium, APT and tungsten powder facilities could be available for war year 1. The APT plant would have to be supplied with concentrate from the stockpile. Thus a three year supply of tungsten concentrate would be required.

More conservative approaches than the one described above would require the stockpiling of additional quantities of material. The exact quantities of material to be stockpiled will be dependent on the mix of DU & W penetrators finally chosen for the various items and on the shortfall in MOB material that results from this mix.

Regardless of the approach taken to providing for MOB material quantity requirements, it would appear to be in the U.S. Government's best interest to retain the DOE facilities for MOB use, provided environmental considerations would allow this option. The use of Canadian tungsten mines for MOB is an open issue. Canadian tungsten mines were not included in estimates of material availability for MOB since no Canadian tungsten mines are currently operating and the 1989 Report to Congress on National Defense Stockpile Requirements (5) did not include reopened Canadian mines in their analysis of stockpile requirements, implying they may not be available to the U. S. during a national emergency.

d. **Excess Depleted Uranium Capacity Available For Other Requirements**

The DOE, in their report (7) on U.S. Government depleted uranium requirements, identified several programs outside the area of penetrators and armor as either users or potential users of depleted uranium. These programs and projected yearly peacetime requirements from 1990 to 2000 show that with the exception of the year 1995, where there is a 375 MT shortfall, U.S. private sector capacity for UF_4 is adequate to meet all peacetime requirements for penetrators, armor and the DOE identified programs. If one considers the current inventory of scrap that

DOE has identified as being able to be used in some of these programs, the shortfall in 1995 can also be easily met. Since the excess capacity for derby and casting is larger than the excess UF_4 capacity, U.S. private sector capacity for these operations would also be available to meet 100 percent of the additional program requirements.

Under MOB conditions, as already pointed out, there would not be any excess capacity available for the DOE identified programs.

5. MANUFACTURING FACILITY REQUIREMENTS

a. Existing Facilities for Depleted Uranium Penetrators

Two facilities exist for manufacture of depleted uranium penetrators, Nuclear Metals Inc. (NMI), located in Concord, Massachusetts, and Aerojet Ordnance Tennessee (AOT) in Jonesborough, Tennessee. Much of the equipment located at these two facilities is government owned.

b. Existing Facilities for Tungsten Penetrator

In the 1977-78 time frame two facilities with government owned equipment were established for manufacture of the 105mm M735 penetrator from tungsten alloy. Shortly after establishment of these two facilities, the Army made the decision to use depleted uranium for large caliber penetrators and these facilities were put in lay-away. These two facilities were located at Teledyne Firth Sterling (TFS) in Levergne, Tennessee, and Kennametal, Slippery Rock, Pennsylvania. Over the years the government has excessed some of this equipment and in some cases TFS and Kennametal have purchased the equipment from the government. The remainder of the equipment is still owned by the government. The TFS line is essentially intact and some capability to manufacture large caliber penetrators still exists at TFS. Kennametal's line has been, for the most part, disbanded and no large caliber penetrator manufacturing capability exists currently at Kennametal. Kennametal has expressed their intention to get out of the tungsten alloy business. Kennametal's exit from the tungsten alloy business would leave two companies as potential manufacturers of tungsten alloy penetrators for DOD. The second company would be GTE Sylvania, Towanda, Pennsylvania.

c. Peacetime Requirements

The peacetime facility costs to manufacture items considered in this study when manufactured from depleted uranium or tungsten are shown in Table III-7. Costs shown for each item are at its

Table III-7

PEACETIME PENETRATOR FACILITY COSTS, $

Item	DU	WA
ATAC	0	5,050,000
COMVAT		
With 919 Same Material	0	0
With 919 Different Material	4,800,000	1,945,000
KEM	500,000	700,000
919	4,800,000	2,005,000
105/120	0	N/A

maximum peacetime production rate using existing facilities to the maximum extent possible. For any combination of items being manufactured from either DU or tungsten, the total cost for facilities could be determined by simply adding costs for each item. There are no cost premiums or savings realized due to any of the combinations.

(1) ATAC Facilities

There is no cost to facilitize for ATAC when using DU because existing 105/120 DU penetrator facilities can be used. Equipment requirements for tungsten facilities for ATAC involve swaging equipment, lathes and ultrasonic inspection equipment.

(2) COMVAT Facilities

COMVAT is to replace the M919 round. If the COMVAT penetrator uses the same material as the M919, COMVAT can be made using the M919 facilities. In this case there would not be any facility cost for COMVAT. If COMVAT penetrator is made from different material than M919, facilities will be required for either the COMVAT tungsten or DU penetrator. The primary reason DU facilities are over twice as much as WA facilities is the M919 requirement for a coating. The M919 penetrator is the first penetrator to require such a coating; and no equipment currently exists for application of this coating. It is expected that the COMVAT penetrator will also require such a coating. Coating equipment cost is estimated at $1.5M to $2.0M.

(3) KEM Facilities

For the purposes of this study only one producer each for DU and WA was chosen to make the KEM penetrator. Quantities were considered too low to split between two manufacturers. A new outgas furnace would be required for DU as the current furnaces would not be able to handle the KEM penetrator length. A new centerless grinding machine and ultrasonic test equipment are the only items of equipment required for the WA production.

(4) M919 Facilities

The M919 penetrator is the first small caliber long rod penetrator to be manufactured. As such, new machining equipment is required whether this penetrator is made from DU or WA. As explained for the COMVAT penetrator, the primary difference in cost is the coating equipment required for the DU penetrator.

(5) 105/120 Facilities

Current facilities at NMI and AOT are adequate to manufacture projected peacetime requirements for the 105/120 penetrators. No additional equipment is required so long as existing capacity at each facility is used to maximum extent possible. This study did not address any potential needs for equipment replacement due to wearing out of equipment.

d. Mobilization Requirements

Facility costs, above and beyond the peacetime facility costs, to manufacture items considered in this study when manufactured from depleted uranium or tungsten are shown in Table III-8. Costs shown for each item are at its maximum mobilization rate using peacetime facilities to the maximum extent possible. For mobilization there are additional costs, above those shown in Table III-8, when combinations of items being manufactured from either DU or tungsten are considered. For this reason it is not possible to simply add item mobilization costs in Table III-8 to determine total facility costs when considering various scenarios or options. Table III-9 shows both the peacetime, mobilization and total facility costs for all combinations of items. The combinations in Table III-9 have been arranged generally in increasing total facility costs (peacetime and mobilization). The ATAC (DU) and KEM and COMVAT (WA) option has the lowest total facility cost at between $9,850,000 to $12,915,000 depending on whether the 919 is made from WA or DU. The most expensive option is all three items made from WA, at a facility cost between $18,800,000 to $21,965,000, again depending on whether the 919 is made from WA or DU.

6. PRODUCTION COST COMPARISON

The most meaningful way to compare costs of DU and WA penetrators is direct head-to-head competitive data. Unfortunately, the only item for which such recent data is available is the Phalanx penetrator. This item showed a per round saving of $1.78 in making the change to WA. Table III-10 shows the actual cost comparison for the Phalanx penetrator and other penetrators where either actual cost data or estimates are available.

ARDEC has done a cost analysis to determine the differential cost between the selection of a depleted uraniun penetrator for the 25mm M919 program in lieu of a tungsten penetrator (XM881). The tungsten alloy penetrator cost was based on estimates provided by the tungsten suppliers. The cost of the DU penetrator was determined from work process sheets generated by

TABLE III-8

MOB PENETRATOR FACILITY COSTS, $

(ADDITIONAL COST TO BE ADDED TO PEACETIME COST TO MEET MOB)

ITEM	DU	WA
ATAC	9,150,000	7,900,000
COMVAT		
919 SAME MATERIAL	0	0
919 DIFFERENT MATERIAL	2,300,000	1,200,000
KEM	800,000	0
919	6,020,000	4,080,000
105	15,300,000	

TABLE III-9
PEACETIME AND MOB FACILITY COST FOR VARIOUS MATERIAL/ITEM MIXES

($ THOUSANDS)

DU ITEMS	DU PEACETIME COSTS	DU MOB COST*	WA ITEMS	WA PEACETIME COST	WA MOB COST*	TOTAL COST
ATAC	0	9,150	KEM & COMVAT 919 ALSO WA	700	0	9,850
ATAC	0	9,150	KEM & COMVAT 919 DU	2,645	1,120	12,915
ATAC & KEM	500	9,950	COMVAT 919 ALSO WA	0	0	10,450
ATAC & KEM	500	9,950	COMVAT 919 DU	1,945	1,120	13,515
ATAC & COMVAT 919 ALSO DU	0	9,500	KEM	700	0	10,200
ATAC & COMVAT 919 WA	4,800	11,800	KEM	700	0	17,300
ATAC & KEM & COMVAT 919 ALSO DU	500	10,750	NONE	0	0	11,250
ATAC & KEM & COMVAT 919 WA	5,300	13,050	NONE	0	0	18,350
KEM	500	0	ATAC & COMVAT 919 ALSO WA	5,050	8,150	13,700
KEM	500	0	ATAC & COMVAT 919 DU	6,995	8,770	16,265
KEM & COMVAT 919 ALSO DU	500	800	ATAC	5,050	7,900	14,250
KEM & COMVAT 919 WA	5,300	3,100	ATAC	5,050	7,900	21,350
COMVAT 919 ALSO DU	0	0	ATAC & KEM	5,750	12,550	18,300
COMVAT 919 WA	1,945	2,300	ATAC & KEM	5,750	12,550	22,545
NONE	0	0	ATAC & KEM & COMVAT 919 ALSO WA	5,750	13,050	18,800
NONE	0	0	ATAC & KEM & COMVAT 919 DU	7,695	14,170	21,865

* ADDED COST TO GET FROM PEACETIME TO MOB QUANTITIES.

Table III-10
DU Versus WA Cost Comparison

Item	DU	WA	Time Period	Source
PHALANX	$ 5.98	$ 4.20	1988	VECP For Change to WA
919/881	7.22	8.46	1987	ARDEC Cost Study
105mm 774 (1)	300.00	———	1982-83	Last 774 Prod. Contracts
105mm 833 (2)	305.00	———	1983	Prod. Contracts
"	216.00	———	1984	" "
"	213.00	———	1985	" "
"	173.00	———	1986	" "
"	226.00	———	1987	" "
120mm 829A1	488.00	———	1989	" "

(1) Wt. - 7.41 lbs., Length 13.65"

(2) Wt. - 8.08 lbs., Length 16.8"

DU manufacturers and experience from other DU production programs. Using this analysis, with adjustments for the current price of tungsten concentrate at $55/standard tungsten unit (stu), the tungsten penetrator was found to be more costly by $1.24 per penetrator.

There is little penetrator cost data for large caliber penetrators made from tungsten alloy. The only production cost data is on the FP105 projectile marketed by Flinchbaugh Products for foreign military sales in the 1983 time period. The penetrator for this round was made by Teledyne Firth Sterling. The weight and length of this penetrator is close to the weight and length of the 105mm M774 penetrator, so a comparison of cost is of interest. In this instance, the DU penetrator is over $100 more costly than the WA penetrator. However, one must keep in mind that a lot of production problems were experienced with the M774. As production proceeded into manufacture of the M833 penetrator, the costs came down significantly to the point where the cost of the FP105 and M833 were approximately equal if comparing constant dollar costs.

The tungsten industry has done their own cost comparison analysis and they have shown the cost of a tungsten large caliber penetrator to be approximately equal to the DU versions. Based on the above considerations, it has been concluded that for the purposes of this study the cost of DU and WA large caliber penetrators are equal.

The current average cost for the 120mm M829A1 penetrator is $488.

7. CONCLUSIONS

a. The following conclusions relative to peacetime considerations have been made:

(1) Material availability is not a problem for either depleted uranium or tungsten.

(2) Private sector capacity with equipment additions, is adequate for either material.

(3) Penetrator facility costs range from $500,000 (KEM @ $500,000), if all items were made from depleted uranium, to $5,750,000 (ATAC @ $5,050,000 + KEM @ $700,000, if all items were made from tungsten.

(4) Private sector material capacity is adequate for DOE identified depleted uranium programs. The DOE programs which could potentially provide workloading for the DU penetrator commercial base are Y-12 and Rocky Flats (FY90 to FY2000) and SSC, HEP and Sub Ballast (FY93 to FY96).

(5) The production cost of depleted uranium and tungsten alloy penetrators is equal for large caliber penetrators. Tungsten alloy penetrators are less costly than depleted uranium in small caliber sizes.

b. The following conclusions relative to mobilization considerations have been made:

(1) Tungsten stockpile additions will be required for mobilization if any penetrators are made from tungsten alloy.

(2) North American capacity is inadequate to meet depleted uranium mobilization requirements for UF_4, derby and casting. This shortfall might be eliminated or significantly reduced if GAU-8 MOB requirements could be reduced and 105mm MOB requirements were brought into line with expected number of vehicles in the field.

(3) U.S. capacity is inadequate to meet tungsten alloy mobilization requirements for APT and tungsten powder.

(4) Penetrator facility costs to get to mobilization rates range from $11,250,000, if all items were made from depleted uranium, to $18,800,000, if all items were made from tungsten.

(5) Under mobilization conditions, there would not be any private sector capacity for DOE identified depleted uranium programs.

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ATTACHMENT A

Process Descriptions

Generic process sequences for manufacture of depleted uranium and tungsten alloy penetrators are shown in Table III-14. Brief descriptions of each process sequence are as follows:

a. Depleted Uranium Process

The process for making depleted uranium penetrators starts with depleted uranium hexafluoride (UF_6) which is a DOE by-product from the uranium enrichment process. UF_6 is government furnished material to the penetrator manufacture. UF_6 is reduced to UF_4 (greensalt) in a chemical reactor. UF_4 is then reduced to metallic uranium in a reduction furnace. This operation involves blending magnesium chips with the UF_4 and placing the mixture in a graphite lined steel vessel. The charged vessel is placed in an electrically heated furnace and brought up to the reaction-ignition temperature (normally 1080^{o}F). The spontaneous exothermic reaction is sufficient to reduce UF_4 and form uranium metal (derby) and magnesium fluoride slag.

Alloying and casting are performed to produce a high quality billet of required chemistry. Because of the chemical reactivity of uranium, melting and casting are performed under vacuum in protected graphite crucibles and molds. Derby and recyclable scrap are charged into the melting crucible together with titanium sponge for alloying. The crucible is placed in a vacuum furnace which is evacuated and heated to melting temperature. When the desired temperature is reached, the molten metal is poured into a nest of molds. The castings are cooled under vacuum for several hours, then removed from the furnace and air-cooled.

The cast billets are either extruded or rolled into rod of appropriate diameter for penetrator manufacture. After blanking into penetrator lengths, the blanks are outgassed in a vacuum furnace to remove hydrogen which can be a cause of embrittlement. The outgassed blanks are rotary straightened to improve straightness for the induction heat treatment operation. In this operation the blanks are heated by passing the blanks through an induction coil which is immediately followed by a water quench. This operation in conjunction with the subsequent ageing heat treatment imparts the desired mechanical properties to the blank.

Table III-11
Generic Processes for Penetrator Manufacture

DU	WA
Starting Material: UF_6	Starting Material: W Concentrate
Convert UF_6 to UF_4	Convert W Conc. to APT
Convert UF_4 to Derby	Convert APT to W Powder
Cast Billets	Blend W & Alloy Powder
Extrude or Roll Billets to Rod	Fill Tubular Container With Powder
Cut Blanks	Isostatic Press
Outgas	Sinter
Rotary Straighten	Vacuum Anneal
Induction Heat Treat	Heat Treat
Rotary Straighten	Face & Center
Age	Rough Turn
Face & Center	Swage
Rough Turn	Finish Machine
Finish Machine	

In preparation for ultrasonic inspection the heat treated blanks are faced and centered and outside diameter machined. After ultrasonic inspection the blanks are machined to final configuration on CNC finish machine lathes.

b. Tungsten Process

Mined tungsten ores are concentrated gravimetrically and by flotation followed by chemical conversion to ammonium paratungstate [5 $(NH_4)_2$ $12WO_3$ $5H_2O$] commonly referred to as APT. APT is calcined in a rotary air furnace which drives off the ammonia and converts the APT to tungsten oxide (WO_3). The WO_3 is then passed through reduction furnaces. In the reduction furnaces, hydrogen gas flows counter to the movement of WO_3 through the furnace which reduces the WO_3 to W powder.

The next step is blending of the W powder with appropriate quantities of alloy powder. Alloying powders are generally iron, nickel, copper and sometimes cobalt. In preparation for pressing, a measured weight or volume of alloyed powder is put into a rubber bag and jolted (vibrated) to a predetermined fill. The bag is then sealed and loaded into an isostatic press. Up to 250 of these compacts are isostatically pressed at one time using water as the pressing medium. A hydrostatic pressure of 30,000psi is the rule.

After isostatic pressing the powder compact has enough strength to support its own weight with careful handling and the rubber bag can be removed. The core blank is now ready for sintering. The core blanks are laid horizontally on a bed of granular alumina on a molybdenum boat and stoked through the sintering furnace. Sintering furnaces are electrically resistance heated and use a hydrogen atmosphere. Sintering temperatures are typically 1350-1560°C.

After sintering, all heavy alloy components are vacuum annealed, mainly to remove entrapped or absorbed hydrogen that might otherwise cause embrittlement. After vacuum annealing, the blanks are heated and quenched into water. This treatment enhances the ductibility of the soon to be cold worked material.

Cold working is accomplished by rotary swaging. In preparation for swaging, the blanks are faced and centered and the O.D. turned. The machined blanks are then rotary swaged to achieve the desired mechanical properties. After swaging the blanks are machined to final configuration on CNC finish turn lathes.

CHAPTER IV

ENVIRONMENTAL CONSIDERATIONS for the KE Penetrator Long Term Strategy Study

1. SUMMARY OF FINDINGS AND RECOMMENDATIONS.

a. The objective of this portion of the study was to perform a preliminary assessment to investigate the environmental and health issues associated with DU and Tungsten penetrator manufacturing, testing and recycle facilities. This work also included an assessment of requirements for decontamination of industrial plant equipment (IPE) at manufacturing sites. Tungsten and DU munitions environmental effects have not been fully characterized by the scientific community and should be further investigated.

b. The work was executed as follows. A generic risk assessment was performed to provide an overall view of environmental and health issues at manufacturing, testing and recycle facilities. This task was performed by means of a literature search with subsequent evaluation of the data collected. In addition to the generic risk assessment, visits were made to a number of manufacturing, testing and recycle sites currently involved with DU and tungsten materials. Detailed technical interviews were conducted at each location with key personnel. Site visit reports were prepared and information obtained was incorporated into the generic risk assessment. See appendix D for the detailed, all-encompassing report. A pathway modelling analysis of DU and W migration at test sites was conducted. See Appendix B for a report on this subject.

2. OVERALL FINDINGS:

a. We conclude that DU and tungsten alloys (WA) are acceptable materials for use as kinetic energy penetrators with regard to human health and the environment. The environmental effects of both materials are rather low when appropriate controls are used. Tungsten and DU munitions environmental effects have not been fully characterized by the scientific community and should be investigated.

b. Based on a preliminary analysis of DU and WA in a test site environment, it was determined from a pathway modelling analysis for both these materials over a long period that these sites should be considered for cleanup of both DU and WA. This analysis was based on many assumptions and was preliminary in nature; however, it does emphasize the need for further site specific analysis before conclusions may be reached concerning requirements for test site and post-combat cleanup of either material. See Appendix B.

c. GENERIC RISK ASSESSMENT FINDINGS

1). MATERIAL PROPERTIES:

DU: Heavy metal, mildly radioactive, highly reactive chemically, pyrophoric, undergoes significant oxidation and corrosion.

TUNGSTEN: Heavy metal, not radioactive, not highly reactive chemically, not pyrophoric, exhibits low corrosion although slight corrosion takes place in sea water, alloyed with nickel and cobalt.

COMMENT: Intrinsic properties of DU require increased safety precautions when compared with tungsten.

2). MATERIAL USES:

DU: Penetrators, ballasts and counter weights, radiation shielding, catalysts.

TUNGSTEN: Carbides (cobalt alloy) for machining and wear resistant materials, welding and hard facing rods, mill products made from pure metal, alloy constituent, chemicals and compounds for metallurgical applications.

COMMENTS: Both materials have commercial applications. Although commercial uses for DU exist, they are minimal when compared with W usage.

3). POTENTIAL HEALTH HAZARDS:

DU: Ionizing radiation causing cancer, chemical toxicity causing kidney damage. Health hazards (i.e. uranium) have been investigated extensively.

TUNGSTEN: Unalloyed tungsten insoluble form: Transient or permanent lung damage and skin irritation.

Soluble Form: Systemic effects involving G.I. Tract and central nervous system; effects on fertility and developmental abnormalities in the musculoskeletal system.

Alloyed with nickel: Suspected carcinogen.

Alloyed with cobalt: Suspected to cause respiratory disease.

The finished alloyed material is considered to cause fewer health effects when compared with the intermediate powder stage where nickel and cobalt are incorporated. Proper assessment of the hazards of tungsten and its compounds requires further scientific study.

COMMENTS: It should be stressed elevated health risk for both materials is due primarily to inhalation of particles. An indepth health physics analysis of the effects of alloyed tungsten penetrator manufacturing and testing is required.

4). <u>REGULATORY ISSUES:</u>

DU: Regulated by NRC. NRC allows higher acceptable lifetime risks than any other federal agency, but has strict licensing requirements for material use. NRC requires exposures be kept "As Low As Reasonably Achievable" (ALARA) due to hypotheses that state: increased risk occurs from increased exposure; and any radiation exposure, no matter how small presents some health risk. Quantitative risk assessment methods show a small number of deaths could result from DU exposure at production sites given continuous employment of a large enough worker population for 20 years. See Appendix D, Volume 2, page D-10, paragraph D.3.1.

TUNGSTEN: Regulated by OSHA. Has no equivalent licensing requirement to DU and regulatory controls are significantly less strict than for DU. Tungsten compounds are regulated by the concept of Threshold Limit Values (TLV), which implies that exposures below the TLV limits cause no health effect. In a quantitative risk assessment where exposures are below the TLV, no deaths are expected, regardless of the worker population.

COMMENTS: Both materials are acceptable for use, as defined by standards set by government agencies.

5). PRODUCTION, STORAGE, DECONTAMINATION, RECYCLE:

DU: Significant controls are required throughout production, storage, decon, recycle. Fires present the potential for significant health consequences and may require cleanup actions. Decon of equipment, if possible, or equipment burials are required. Low Level Waste (LLW) generated requires special burial.

TUNGSTEN: Significant controls not required outside the powder metallurgy manufacturing stage. Potential effects of fire are less severe than DU. Some compounds are recommended for disposal in a landfill approved for disposal of hazardous wastes. Some decon of equipment may be required; however, decon of equipment is not considered a significant issue.

COMMENTS: DU fire risks are considered manageable by regulatory agencies due to improbability of occurrence.

6). RANGE TESTING:

DU: Testing effects have been characterized and extensive safety precautions are in place. Penetrators are fired against armor in targets with environmental controls. Soft target testing results in penetrators and fragments dispersed in the open environment on sites controlled by the government. There are no indications (from limited, but substantial environmental work performed to date) that soft target testing presents a significant environmental threat. It is likely that DU recovery from ranges will be required, if not for environmental reasons, then for regulatory and political concerns.

TUNGSTEN: Testing effects have not been characterized. Current procedures require no environmental safety precautions. Health hazards to personnel of hard target testing are unknown. It is assumed, but not proven, that tungsten penetrators and fragments dispersed on open ranges will not have environmental effects. We doubt that tungsten recovery from ranges will be necessary. However, we have no conclusive evidence to support this statement. Considering analysis performed in Appendix B, it is necessary to study WA test site cleanup needs.

COMMENTS: DU penetrators & fragment recovery costs can be anticipated, while tungsten retrieval of penetrators & fragment recovery will probably not be required. Studies to decide the necessity for tungsten recovery are needed.

7). COMBAT:

DU: Exposures to military personnel may be greater than those allowed in peacetime, and could be locally significant on the battlefield. Clean-up of penetrators and fragments, as well as impact site decon will likely be required.

TUNGSTEN: Potential exposures to respirable particles from penetrator impacts. Cleanup and decon are not likely to be required; but, further study is recommended.

COMMENTS: A difference in cleanup requirements is the significant finding from this comparison. Additional information on DU combat exposures will be needed for post-combat debriefings and actions. A study is recommended to determine likely DU combat exposures.

8). PUBLIC RELATIONS:

DU: Public relations efforts are necessary due to the public's perceived fear of radioactivity. Fielding and combat activities present the potential for adverse international reaction.

TUNGSTEN: Public relations efforts are not needed.

COMMENTS: Potential exists for heightened public reaction to DU manufacturing and testing perceived risks.

d. GENERIC RISK ASSESSMENT CONCLUSIONS:

1). Both DU and tungsten present low, acceptable risks for use in penetrators.

2). There are advantages of an environmental nature to tungsten over DU. These advantages are as follows:

a) Less management control during manufacture since tungsten is not radioactive.

b) Risk of fire during manufacturing and its consequences are less for tungsten.

c) Public relations efforts are not needed for tungsten.

d) Significant decontamination and disposal (D&D) efforts at tungsten manufacturing sites are not necessary.

e. MANUFACTURING SITES FINDINGS:

1). Production of DU and tungsten penetrators appears to be in accordance with applicable regulations and we have identified no unmanageable impacts to public health and the environment.

2). Fires at DU manufacturing facilities could present a potential danger to nearby populations, involve considerable cleanup costs and have an adverse public reaction. The probability of fires is extremely low.

3). Future regulatory changes, by the NRC, apparently will present no obstacles to continued DU production, although uncertainty exists regarding regulation changes.

4). Low level waste amounts for disposal have steadily decreased at both DU manufacturing sites.

5). Significant DU process technology advancements have been developed which can minimize or eliminate metal waste disposal.

6). During tungsten production, nickel and cobalt are primary potential pollutants.

7). All tungsten scrap and metal is recycleable into the tungsten reclaim process.

8). Measured and estimated airborne concentrations indicate that exposures during tungsten alloy processing are within current limits.

9). A decontamination and disposal (D&D) site closure plan, with financial backing details, is required at each DU site. Prior cleanup efforts involved government participation through overhead allocation.

10). Decontamination of a portion of the tungsten manufacturing facility is expected to be necessary (Nickel & Cobalt powder areas).

f. MANUFACTURING SITES RECOMMENDATIONS:

1). Investigate methods to decrease the risk and environmental consequences of DU manufacturing facility fires. Methods used in the plutonium industry may be applicable and technology transfer between industries should be investigated.

2). Ensure, through additional investigation and continued oversight, that regulatory changes will not result in production problems with the DU manufacturing base.

3). Establish projects to implement process technology improvements which minimize DU radiological (or low level) waste disposal.

4). Investigate on a broader industrial wide basis the exposure levels of tungsten workers.

5). The subject of D&D at sites must be addressed as a result of NRC regulations changes.

g. TEST RANGE FINDINGS:

1). Testing of DU penetrators currently takes place in accordance with applicable regulations and appears to present no significant danger to public health or the environment.

2). Enclosed hard target testing is conducted in accordance with applicable regulations and with generally suitable environmental precautions.

3). Significant site specific improvements are required at each of the range facilities visited.

4). Aberdeen, Jefferson and Yuma Proving Grounds have been used for penetrator testing and therefore contain scattered areas of DU materials. It appears that recovery of DU penetrators and fragments will eventually be required; however, additional cleanup over and above recovery may not be necessary, assuming that sites will not be released for uncontrolled use. Therefore, no reliable cost estimates are available. Any range remedial actions are complicated by the unexploded ordnance issue. Clean-up cost estimates cannot be considered representative of the true costs as the clean-up standard and method postulated may not be appropriate, feasible, or required.

5). Factors that influence efforts toward penetrator recovery include possession limits of the site imposed by the NRC license.

6). Tungsten contamination of ranges is not perceived in the testing community as an environmental concern, however there is no definitive scientific proof to substantiate this conclusion, and further study is recommended. See Appendix B.

7). Detailed DU environmental studies regarding worker exposure and test range status are already in progress at most sites.

h. TEST RANGE RECOMMENDATIONS:

1). Upon conclusion of the studies mentioned in paragraph 2.g. (above) strategies for remediation of the ranges, if necessary, should be developed. Typical Remedial Investigation/Feasibility Study (RI/FS) procedures could be implemented.

2). Soft target range testing strategy should be further analyzed to minimize environmental impacts from continued testing. Consideration should be given to maximizing penetrator recovery by restricting testing to ranges without unexploded ordnance (UXO). Improvements can also be made to enclosed testing facilities. Future D&D issues for ranges must be addressed since permit reissue will require such consideration.

3). Site specific soft target range improvements should be considered. Catch box design and impact medium should be investigated for each site and penetrator material. The purpose of the catch box is to maximize recovery while also minimizing fragmentation.

4). Investigate environmental effects of tungsten range testing.

5). Monitoring should consider DU as well as tungsten, nickel and cobalt migration.

6). Clean-up efforts at Yuma should be funded to use the Gold Recovery equipment, already demonstrated, which is on site (YPG). See Volume 3, page II-149, Appendix D.

i. RECYCLE AND DECONTAMINATION FINDINGS:

1). Facilities to implement recycle of munitions and decontamination of equipment are, at best, only at concept stage of development. This presents concerns regarding optimal life cycle control of penetrators.

2). Decontamination studies for IPE with recommendations have been prepared by AMCCOM. Decisions have not been made for disposition of contaminated equipment currently in storage.

3). Studies have demonstrated that approximately 85% of a typical equipment item can be successfully decontaminated at a reasonable cost.

4). Closure estimates are available for DU manufacturing facilities.

5). Closure cost for tungsten penetrator facilities could conceivably be incurred for remediation of heavy metal (powder alloy process) contamination.

j. RECYCLE AND DECONTAMINATION RECOMMENDATIONS:

1). Studies of projectile metal parts demil resulting in optimal recycle return must be conducted.

2). A study of the benefits of equipment decontamination vs. burial should be conducted. Methods and site of decon should be investigated.

3). A study of the benefits of demil & recycle of old tungsten penetrators should be conducted.

4). Comprehensive investigation of the above issues should be implemented.

k. LOW LEVEL WASTE FINDINGS:

1). Changes in Army radioactive waste disposal management will occur as a result of the Low Level Waste Act Policy Amendments of 1985 which establishes compacts and regional disposal sites. Ramifications of this law remain uncertain.

2). Facilities will face large increases in radioactive waste management costs in the future. Available space for burial will be limited.

3). Pyrophoricity of DU waste with potential accidental fires remains a concern. Methods for resolving this issue have been proposed. (See Appendix D).

4). Waste minimization and volume reduction technologies are available within the DU industry and are not being fully implemented at Army owned facilities. Manufacturing sites are actively investigating these measures.

1. <u>LOW LEVEL WASTE RECOMMENDATIONS:</u>

1). Ensure that suitable DU waste disposal plans with regard to the Low Level Waste Act Policy Amendments of 1985 are in place.

2). Investigate and implement technologies for waste mininization, volume reduction and reducing pyrophoricity of wastes.

CHAPTER V
COST ANALYSIS
for the
KE Penetrator Long Term Strategy Study

1. Introduction

As part of the KE materials study, a rough order of magnitude (ROM) estimate of the cost differential between DU and WA rounds was made for the ATACS, KEM and COMVAT systems. Cost differentials for each portion of the life cycle were considered, including R&D, stockpile, facilitization, manufacture, operations and support, and demilitarization. Other issues such as potential cleanup costs for manufacturing and test sites were also addressed. In addition, a suggestion was made during a preliminary briefing of this study that a "warfighting" cost differential be developed, to consider the impact of fighting a major war with either DU or WA ammunition. Although this analysis was carried out (ref 3) it was later rejected as an appropriate measure of cost difference. The following sections provide detailed discussions of cost differentials for each individual portion of the life cycle. A summary of results and discussion of data gaps concludes the cost analysis chapter.

2. R&D Cost Differential

R&D cost differences between DU and WA occur in two general areas: additional safety costs related to working with DU and additional R&D programs related to improving the performance of WA.

The issue of safety-related costs has been examined in detail as part of the 25mm M919 analysis (refs 1 and 2), and results of those studies form the basis for the safety data presented here. Safety costs related to DU R&D programs include additional personnel, equipment and tests required to monitor radiation, work with DU materials, inspect waste disposal procedures, and obtain NRC licenses for storage and deployment (ref 1).

The net R&D safety cost differential was based on reference 2 and amounts to $1 million in 1989 dollars. It was estimated that this same cost differential would apply to all three weapon systems - ATACS, KEM, and COMVAT.

Conclusions from the penetrator performance analysis discussed earlier in this report indicate that WA penetrators may perform less effectively than DU against threat targets. In particular, for the ATACS weapon system there is a good chance that a WA penetrator may perform inadequately against the target. It was estimated in the technology section of this report that a successful R&D program to improve the material properties of WA (and increase its performance) would cost between 30 and 74 million dollars, corresponding to low and high chance of success,

respectively. This amount is included as an R&D cost differential for ATACS in favor of DU.

Although DU also outperforms WA in the KEM and COMVAT systems, both penetrator materials may achieve acceptable penetration levels against their threats. Thus no cost differential for improving its material properties was assessed for these systems.

At present, there is some question as to whether a DU KEM round would need a special (DU licensed) test range built, or could it use existing test facilities (e.g. White Sands Missile Range). The assumption used in this cost analysis was that no new test site would be built. If it is later determined that a new site would be necessary then the costs for construction (and later cleanup) would amount to a cost differential in favor of WA for KEM.

Table V-1 summarizes the R&D cost differential for ATACS, KEM and COMVAT.

3. Stockpile Cost Differential

As was previously discussed in the Industrial Base portion of this report, there is an adequate supply of both Tungsten and DU raw materials to meet normal peacetime production rates. However, under mobilization conditions, additional amounts of raw materials and processing facilities would be needed to meet increased production demands.

Details of the stockpile costs for MOB are presented in tables V-2,V-3, and V-4. Additional information regarding this data and method of analysis are found in the Industrial Base section.

Table V-2 shows the DU stockpile analysis. Key points include:

(1) The existing UF6 stockpile is sufficient to handle MOB situations at no cost to the Army.

(2) In the event of a "MOB situation", additional facilities would have to be built to process the raw material.

(3) It would be prudent for the Army to maintain the DOE's Fernald Facility for use in a MOB situation.

(4) The Canadian processing capacity (Derby and Casting only) may not be available for US use and was not included in this analysis.

Table V-3 presents details of the WA stockpile analysis. Key points include:

Table V-1 **R&D Cost Differential ($M)**

(DU$ - WA$)	ATACS	KEM	COMVAT
(1) Safety Monitoring[1]			
(a) Engineering Studies	.11	.11	.11
(b) Prototype Manufacture	.12	.12	.12
(c) Testing	.19	.19	.19
(2) Tests for NRC license	.58	.58	.58
(3) R&D Program to Defeat Threat	(30-74)[2]	0[4]	0
R&D TOTAL	(29.-73.)[3]	1.0	1.0

[1] Including monitoring of facilities, radiation exposure, & waste disposal procedures

[2] WA material properties development program needed to improve penetration. Dollar range corresponds to low to high probabilities of achieving success.

[3] Terms in parenthesis favor D.U.

[4] Assumes test site is available for KEM

Table V-2: DU Stockpile for Mobilization

Material Processing Step	Mob. Rqt. (MT/Year)	Max US[1] Processing Capacity (MT/Year)	Difference (MT/Year)	Cost to Facilitize ($/MT/Yr)	Total New[3] Facility Cost for Mobilization
UF6[2]	-	-	0	-	0
UF4	15,745	6,683	9062	1,340	$12.1 M
Derby	15,745	13,638	2,107	430	$0.9 M
Cast Ingot	22,093	19,022	3,071	500	$1.5 M
				Total	$14.5 M

	Fraction of Mob. Rqt.	Share of New Fac. Cst. ($M)
ATACS	.0895	1.3
KEM	.0356	0.5
COMVAT	.0216	0.3

1 *Assumes DOE Fernald Facility is maintained for DOD use during mobilization. (The Canadian derby and casting capacity of 1380 MT/Year was not included).*

2 *Existing UF6 stockpile is sufficient for mobilization. It is provided free to the DOD.*

3 *These new processing facilities might not have to be built until the presumed "warning year" before war actually starts.*

Table V-3: Tungsten Stockpile for Mobilization [1]

Material Processing Step	Mobilization[2] Requirements (MT/Yr)	Cost to Stockpile ($/MT)	Total[3] Stockpile Costs ($M)	Cost to Facilitize ($/MT/Yr)	Total New Facilitization Cost ($M)
W Conc.	1900	7,629	43.5 (3 yrs)[4]	47,000 (2.5 yrs)[5,6]	0.0
APT	3646	11,245	0.0	3,500 (1 yr)[6]	12.8
W Powder	3537	22,049	0.0	900 (1 yr)[6]	3.2
		Total	43.5	Total	16.0

	Fraction of Mobilization Requirement	Share of Stockpile Costs ($M)	Share of New Facilitization Costs ($M)	Share of Total Costs ($M)
ATACS	0.41	17.8	6.6	24.4
KEM	0.21	9.1	3.4	12.5
COMVAT	0.12	5.2	1.9	7.1

1 *Raw material stockpile of concentrate should be created as soon as possible; new facilities construction might be "deferred" until the presumed "warning year" before hostilities begin.*

2 *Current W processing capacity for MOB will not be available for penetrators.*

3 *Number of years stockpile must last depends upon time required to build processing facilities and assumes a "warning year" is available in which to build facilities.*

4 *Required years of stockpile*

5 *Represents cost to open US mines.*

6 *Time required to build.*

(1) There is no stockpile of raw material available for penetrators during MOB.

(2) A raw material stockpile consisting of 3 years supply of W concentrate is necessary to maintain a three year MOB production capability.

(3) It appears prudent for this stockpile to be created as soon as possible, as increases in W imports may no longer be obtainable during the presumed "warning year" that precedes open hostility.

(4) In the event of a "MOB situation", additional facilities would have to be constructed to process the raw material.

(5) In a MOB situation, it would take too long (2 1/2 years) to open new US tungsten mines, nor would this be the most cost effective solution.

Table V-4 summarizes the DU - WA stockpile cost differential data for the ATACS, KEM, and COMVAT systems. Cost advantages favoring DU are in the tens of millions of dollars.

4. <u>Facilitization For Manufacturing - Cost Differential</u>

The costs to build new facilities to manufacture penetrators for ATACS, KEM, and COMVAT will vary depending on the choice of penetrator material. MOB and peacetime facilitization costs for any combination of DU and WA for the above three systems, as well as for the 25mm M919, have been provided in the Industrial base section of this report. Table V-5 summarizes cost information for four of the more likely weapon system-penetrator material combinations. Depending on the case, ATACS, KEM and COMVAT are individually varied to be either DU or WA (while the M919 is assumed to remain DU). By subtracting one case from another it is possible to calculate DU - WA cost differentials for each system. For example, case A shows peacetime and MOB facilitization costs assuming ATACS is DU while KEM and COMVAT are WA; case B assumes all three systems will be WA. Since only ATACS changes materials for these two cases, the ATACS cost differential is determined by subtracting case B costs from case A costs. The net result is a $9 million advantage to DU, divided up as a $5.1 million advantage for construction costs to meet peacetime production rates and a $3.9 million advantage for construction costs to meet mobilization production rates. Cost differentials for KEM and COMVAT are found in a similar manner. COMVAT shows a $2.7 million advantage in favor of DU, while KEM shows a $1.1 million advantage to WA. The unique aspect to KEM is that the peacetime cost differential slightly favors DU ($0.2 million) while the MOB cost differential favors WA ($1.3 million). If a "warning year" is assumed prior to actual war, MOB facilities construction might be deferred until that time.

TABLE V-4: STOCKPILE COST DIFFERENTIAL FOR MOB ($M)

COST DIFFERENTIAL FOR :	ATACS	KEM	COMVAT
RAW MATERIAL STOCKPILE	(17.8)	(9.1)	(5.2)
NEW PROCESSING FACILITIES *	(5.3)	(2.9)	(1.6)
TOTAL DIFFERENTIAL	(23.1)	(12.0)	(6.8)

TERMS IN PARENTHESES FAVOR DU

* NEW FACILITIES CONSTRUCTION MIGHT BE DEFERRED UNTIL THE PRESUMED "WARNING YEAR" BEFORE HOSTILITIES BEGIN

TABLE V-5: FACILITIZATION COST ANALYSIS

	CASE A	CASE B	CASE C	CASE D
DU SYSTEMS	ATACS M919	M919	ATACS COMVAT M919	ATACS KEM COMVAT M919
WA SYSTEMS	KEM COMVAT	ATACS KEM COMVAT	KEM	
FACILITIZATION COSTS:				
- PEACETIME	$2.6M	$7.7M	$O.7M	$0.5M
- MOB	$10.3M	$14.2M	$9.5M	$10.8M
TOTAL	$12.9M	$21.9M	$10.2M	$11.3M

Table V-6 presents the final facilitization cost differentials for ATACS, KEM and COMVAT for both peacetime and MOB production rates.

5. Manufacturing and O&S Cost Differentials

With the exception of some safety-related costs for DU, information collected during the Industrial Base portion of this study showed no clear picture as to which material might provide the cheaper penetrator to manufacture. For large caliber penetrators such as ATACS and KEM, most Army and contractor cost estimates generally showed no net manufacturing advantage for either DU or WA(e.g. Refs. 3 and 4).

At small calibers, however, analyses of manufacturing cost differentials have reached varying conclusions, ranging from approximately $1. per round in favor of DU for the 25mm M919 (Refs. 1, 2, and 8), to several dollars per round in favor of WA for the 20mm Phalanx. Based primarily on extrapolating Phalanx cost data, the Refractory Metals Association estimates that the 45mm COMVAT could have a manufacturing cost differential of $10. per round in favor of W (Ref 7). Although basing the manufacturing cost differential for COMVAT on data extrapolated from smaller caliber Phalanx and M919 projectiles may not be entirely accurate, the KE Materials Study Group believes a manufacturing cost differential range of zero to ten dollars per round in favor of W is reasonable for COMVAT.

Based on data provided in the 25mm M919 studies (ref 1 and 2), additional safety-related costs are incurred by DU penetrators during manufacture and O&S. These costs were assumed to be the same for ATACS, KEM and COMVAT and are caused by the need for personnel and equipment to do radiological monitoring, handle contaminated materials, and perform other regulatory activity during manufacture, LAP, lot acceptance testing, and surveillance testing.

Cost differentials in the manufacturing phase were totaled over 10 years of production, while cost differentials during O&S were totaled over a presumed 20 year "life" of the projectile. Table V-7 summarizes the manufacture and O&S cost differentials, which amount to $3.3 million in favor of WA for ATACS and KEM. COMVAT, based on 4 million rounds being produced over ten years, has a cost differential range of $3.3 million to $43. million in favor of WA.

6. Demil Cost Differential

The subject of demil costs for KE projectiles is currently receiving increased interest. Precise estimates on how much it actually costs to demil a DU or WA penetrator are lacking. In

TABLE V-6: FACILITIZATION COST DIFFERENTIAL ($M)

	ATACS	KEM	COMVAT
CASES USED*	A-B	D-C	C-A
COST DIFFERENTIAL FOR:			
- PEACETIME	(5.1)	(0.2)	(1.9)
- MOB	(3.9)	1.3	(0.8)
TOTAL DIFFERENTIAL	(9.0)	1.1	(2.7)

TERMS IN PARENTHESES FAVOR DU

*SEE PREVIOUS TABLE

Table V-7

MANUFACTURE AND O&S COST DIFFERENTIAL ($M)

MANUFACTURE CARTRIDGE: (10 YEARS OF PRODUCTION)	ATACS	KEM	COMVAT	COMMENT
(a) MANUFACTURE PENETRATOR	0.	0.	0-40.	*2
(b) LOAD,ASSEMBLE,PACK CARTRIDGE	0.7	0.7	0.7	*1
(c) LOT ACCEPTANCE TESTS	1.3	1.3	1.3	*1
O & S (20 YEARS SURVEILLANCE TESTING)	1.3	1.3	1.3	*1
TOTAL	3.3	3.3	3.3-43.	

*1 RADIOLOGICAL MONITORING, ADDITIONAL REGULATORY ACTIVITY AND HANDLING OF CONTAMINATED MATERIALS NECESSARY FOR DU

*2 BASED ON 4 MILLION COMVAT ROUNDS BEING PRODUCED OVER 10 YEARS @ 0 TO 10 DOLLARS PER ROUND COST DIFF.

particular, accurate quantitative answers to the following questions must be determined:

(1) What are the cartridge disassembly costs for KE penetrators of various calibers?
(2) Will the Army actually realize a net profit if WA rounds are demilled and sold as scrap?
(3) What is the scrap market for a demilled DU round?
(4) What should be done with the (possibly contaminated) fins and sabots of DU rounds? (costs?)

Various proposals to address some of these questions have recently been formulated; however, the actual investigations may take as long as a year to complete (ref 5).

Previous studies have investigated the demil cost differential between DU and WA projectiles (refs 1, 2, and 4). Ref 4 was a 1980 ARDEC analysis of large caliber penetrators, while refs 1 and 2 were ARDEC studies of the 25mm XM919 (DU) /XM881 (WA) projectile, performed in 1984 and updated in 1987, respectively. Since the primary aim of these studies was to arrive at a net DU - WA cost differential, not all aspects of the demil process were discussed in detail.

The dominant factor in these cost differential analyses was the large scrap value of W vs presumed disposal costs for DU components. It was estimated in the 1980 study that the net cost <u>advantage</u> from demilling and scrapping a large caliber WA penetrator would amount to $53.24 per penetrator, while disposing of the components of a DU round would produce a net <u>loss</u> of $2.98/round. The overall demil cost differential was $56.22 per round, in favor of WA. If this data were updated to 1989 dollars and current W prices ($55. per STU), the net demil cost differential is reduced to $27.15 per round in favor of WA, as shown in Table V-8. This estimate does not consider any possible recycle value for DU, and could be substantially changed if economical recycling of obsolete DU penetrators were achievable.

Based on the limited amount of data currently available, and pending completion of more detailed demil studies, it was assumed for the purposes of this analysis that the $27.15/round cost differential would be applicable to the ATACS round. Cost differentials for KEM and COMVAT were estimated from the ATACS value by factoring in the ratio of the weight of each type of penetrator relative to the weight of the ATACS penetrator. After multiplying by the total number of rounds being demilled, net cost differences for these three systems ranged from $6 million to $12 million in favor of WA. This data is summarized in table V-8.

7. <u>Cleanup Cost Differential</u>

Environmental issues are becoming sources of increasing concern to everyone, including the Army. The chemical and

Table V-8 DEMIL COST DIFFERENTIAL

	COST/RD *1		TOT RDS	TOT COST		DIFF:
	DU	WA		DU	WA	DU - WA
ATACS	$4.65	($22.6)	440K	$2.0M	($9.9M)	$11.9M

	DEMIL WT RATIO *2	COST DIFF
ATACS	1.0	$11.9M
KEM	0.52	$6.3M
COMVAT	0.61	$7.3M

*1 COST/RD (ATACS) BASED ON 1980 ARDEC REPORT ON KE MATERIALS ALTERNATIVES, UPDATED TO 1989 DOLLARS AND WITH TUNGSTEN PRICE ADJUSTED FROM $130./STU TO $55./STU.

*2

$$(\text{DEMIL WT RATIO})_X = \left(\frac{\text{RDS}_X}{\text{RDS}_{\text{ATACS}}}\right) \cdot \left(\frac{\text{WT}_X}{\text{WT}_{\text{ATACS}}}\right)$$

radioactive hazards associated with KE penetrator test sites and manufacturing facilities have already been described in the environmental section of this report.

Future cleanup costs for facilities processing DU material or manufacturing DU penetrators may cost many millions of dollars. The extent of clean-up required at the test sites is a subject which is under investigation by TECOM. It is premature to attempt a cost estimate at this time. Whatever the total clean-up costs are determined to be, they represent costs to clean up largely pre-existing conditions which switching from DU to WA would not change. Also, it is not clear whether the Army will incur all, or any, of the clean-up costs at the privately owned sites.

If a new test range to fire DU KEM is required, this would be an exception to the above assumptions. As was discussed in the R&D section of this chapter, both construction and clean up costs for a new DU missile test range would create a significant cost differential in favor of WA.

8. Total Life Cycle Cost Differential

Table V-9 combines the cost differentials from all the preceding sections. The overall cost differential for ATACS (46 to 90 million dollars) is in favor of DU. The lower value assumes the successful completion of a high risk R&D effort to improve WA, while the larger value is for a low risk R&D effort for WA.

The net cost differential for KEM ($0.3 million in favor of DU) is inconsequential.

The cost differential range for COMVAT (2 to 42 million dollars in favor of WA) varies from being relatively inconsequential at the low end, to being in favor of WA at the high end. This variation is primarily due to the manufacturing cost differential, which was estimated might vary anywhere from zero to $10. per round in favor of WA.

9. Cost Differential Summary and Issues

ATACS cost differential (46 to 90 million dollars) significantly favors DU. The primary reasons for this are:

(1) Expensive R&D program to improve WA material properties appears necessary.

(2) Expensive W stockpile for MOB appears necessary.

The KEM cost differential favors neither material.

Table V-9 Total Life Cycle Cost Differential ($M)

	ATACS	KEM	COMVAT
• R&D			
Safety Monitoring/Testing	1.0	1.0 [1]	1.0
R&D Program to Improve Material	(30.-74.) [2]	0.0	0.0
Total R&D	(29.-73.)	1.0	1.0
• Stockpile (MOB)			
Raw Material	(17.8)	(9.1)	(5.2)
Processing Facilities	(5.3)	(2.9)	(1.6)
Total Stockpile	(23.1)	(12.0)	(6.8)
• Facilitization:			
Peacetime Rates	(5.1)	(.2)	(1.90)
MOB Rates	(3.9)	1.3	(0.8)
Total Facilities	(9.0)	1.1	(2.7)
• Manufacturing Cartridge [3]			
Safety Monitoring/Testing	2.0	2.0	2.0
Production Process	0.0	0.0	0-40. [4]
Total Manufacturing	2.0	2.0	2.0-42.
• O&S (Safety Monitoring/Testing)	1.3	1.3	1.3
• Demilitarization	11.9	6.3	7.3
Total "Life Cycle" Cost Differential	(46.-90.)	(0.3)	2.1-42.

[1] Assumes test sites are already available for KEM (DU)
[2] High to low risk R&D efforts for WA
[3] 10 years of production cost differential
[4] Mfg cost differential range for COMVAT: 4 million rounds • 0 to $10. per round

The cost differential for COMVAT (2 to 42 million dollars in favor of WA) is sensitive to the relative penetrator manufacturing costs of the two materials. If the manufacturing costs are the same, then the Total Life Cycle Cost Differential is essentially zero; if the manufacturing costs favor WA, the Total Life Cycle Cost Differential rapidly increases in favor of WA.

Areas of high cost differentials include:

(1) WA R&D program (for ATACS)

(2) MOB costs (raw materials and facilities)

(3) Possible manufacturing cost differential (for COMVAT)

(4) Demil.

In general, detailed cost analyses and validated estimates were not generated during this study. The ROM cost differentials presented are primarily the result of gathering and updating existing cost data.

A detailed manufacturing cost analysis for COMVAT would be useful in more accurately determining the total cost differential for that system.

More detailed demil cost data are needed for large caliber rounds. Studies investigating DU reclamation options are just getting under way.

More detailed estimates of the costs to clean up manufacturing facilities and test sites are needed (although this may not affect the cost differential between DU and WA). Studies in these areas have recently been mandated by environmental agencies.

A determination of whether the testing requirements for a DU KEM can be satisfied using existing test ranges (e.g. White Sands) should be made. Costs involved with construction (and later cleanup) of a new DU test site could shift the cost differential in favor of WA.

References for Chapter V

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CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS for the KE Penetrator Long Term Strategy Study

1. CONCLUSIONS:

a. <u>Performance Conclusions</u>

1). Details of the BRL Performance Analysis are classified. An unclassified summary of the conclusions is as follows:

a). KE systems using DU penetrators outperform those with WA penetrators given the same system constraints, for both RHA and the range targets addressed. The gap for these range targets is at least as large as it is for RHA.

b). The specific designs analyzed show the inherent terminal ballistic gap could be overcome by using higher technology/performance projectiles and/or launchers for WA systems.

c). When performance requirements exist to extract the maximum performance from KE systems like KEM, ATAC and COMVAT, the KE penetrator material of choice will remain DU.

2). There are alternate launch technologies in development which may offer higher energy or velocity on target than those assumed for the three weapons systems studied. However, application of any of these technologies within the fielding timeframe of interest is considered high risk. The launch capabilities assumed in the BRL Performance Analysis represent the best technologies likely to be available for fielding in the 1995-2000 timeframe.

3). WA material studies presently maturing are not expected to result in any substantial closure of the ballistic performance gap between DU and WA. These same WA studies are expected to, and have already, substantially improved mechanical properties, which may result in somewhat enhanced ballistic performance against some targets. Optimized WA/sabot assembly designs may close the gap further. However, no substantial evidence was found that this improvement will be significant, or early enough to provide a low- to medium-risk alternative for large caliber gun systems within the timeframe considered in this study.

4). A long-range material development effort focused on terminal ballistic improvements for WA penetrators against advanced targets is needed. Such an effort has been recommended in the ARDEC/BRL/MTL Tungsten Coordination Committee's Final Report.

b. Industrial Base Conclusions

1). Peacetime:

a). Neither material availability, nor production capability would be a major problem for DU or WA penetrators. Some additional equipment would be required, depending on the combination of material choices for each weapon system. Penetrator facility costs would range from $0.5M, if all three future weapon systems were DU, to $5.75M if all were WA.

b). Private sector material capacity is adequate for DOE identified DU programs. There are DOE requirements which could help in the near term workloading problems being identified by the private sector. Technical and programming considerations would have to be addressed.

c). Production costs for DU and WA are expected to be about equal for large caliber penetrators. For small caliber, WA penetrator production appears to be less costly.

2) Mobilization

a). Additional tungsten stockpile will be required for mobilization if penetrators are made from tungsten alloy.

b). North American capacity is inadequate to meet depleted uranium mobilization requirements for UF 4, derby and casting. This shortfall might be eliminated or significantly reduced if GAU-8 MOB requirements could be reduced and 105mm MOB requirements were brought in line with the expected number of vehicles in the field.

c). U.S. capacity is inadequate to meet tungsten alloy mobilization requirements for APT and tungsten powder.

d). Penetrator facility costs to get to mobilization rates range from $11,250,000, if all items were made from depleted uranium, to $18,800,000, if all items were made from tungsten.

e). Under mobilization conditions, there would not be any private sector capacity for DOE identified depleted uranium programs.

c. <u>Environmental Conclusions</u>

1). Overall Findings:

a). We conclude that DU and tungsten alloys are acceptable materials for use as kinetic energy penetrators with regard to human health and the environment. The environmental effects of both materials are rather low when appropriate controls are used. DU and WA munitions environmental effects have not been fully characterized by the scientific community and should be further investigated.

2). Manufacturing Sites Findings:

a). Production of DU and tungsten penetrators appears to be in accordance with applicable regulations and we have identified no unmanageable impacts to public health and the environment.

b). Fires at DU manufacturing facilities could present a potential danger to nearby populations, involve considerable clean-up costs and have an adverse public reaction. The probability of fires is extremely low.

c). Future regulatory changes, by the NRC, apparently will present no obstacles to continued DU production although uncertainty exists regarding regulation changes.

d). Low level waste amounts for disposal have steadily decreased at both DU manufacturing sites.

e). Significant DU process technology advancements have been developed which can minimize or eliminate metal waste disposal.

f). During tungsten production, nickel and cobalt are primary potential pollutants.

g). All tungsten scrap and metal is recycleable into the tungsten reclaim process.

h). Measured and estimated airborne concentrations indicate that exposures during tungsten alloy processing are within current limits.

i). A Decontamination and Disposal (D&D) site closure plan with financial backing details, is required at each DU site.

3). Test Range Findings:

a). Testing of DU penetrators currently takes place in accordance with applicable regulations and appears to present no significant danger to public health or the environment.

b). Enclosed hard target testing is conducted in accordance with applicable regulations and with generally suitable environmental precautions.

c). Significant site specific improvements are required at each of the range facilities visited.

d). Aberdeen, Jefferson and Yuma Proving Grounds have been used for penetrator testing, and therefore contain scattered areas of DU materials. It appears that recovery of DU penetrators and fragments will eventually be required; however, additional clean-up over and above recovery may not be necessary, assuming that sites will not be released for uncontrolled use. Any range remedial actions are complicated by the unexploded ordnance issue. Clean-up cost estimates cannot be considered representative of the true costs as the clean-up standard and method postulated may not be appropriate, feasible or required. Therefore, no reliable cost estimates are available.

e). Factors that influence efforts toward penetrator recovery include possession limits of the site imposed by the NRC license.

f). Tungsten contamination of ranges is not perceived in the testing community as an environmental concern. However, there is no definitive scientific proof to substantiate this conclusion and further study is recommended.

g). Detailed DU environmental studies regarding worker exposure and test range status are already in progress at most sites.

4). Recycle and Decontamination Findings:

a). Facilities to implement recycle of munitions and decontamination of equipment are, at best, only at concept stage of development. This presents concerns regarding optimal life cycle control of penetrators.

b). Decontamination studies for industrial plant equipment (IPE), with recommendations, have been prepared by AMCCOM. Decisions have not been made for disposition of contaminated equipment currently in storage.

c). Studies have demonstrated that approximately 85% of a typical equipment item can be successfully decontaminated at a reasonable cost.

d) Closure cost estimates are available for DU manufacturing facilities.

e). Closure cost for tungsten penetrator facilities could conceivably be incurred for remediation of heavy metal (powder alloy process) contamination.

5). Low Level Waste Findings:

a). Changes in Army radioactive waste disposal management will occur as a result of the Low Level Waste Act Policy Amendments of 1985 which establish compacts and regional disposal sites. Ramifications of this law remain uncertain.

b). Facilities will face large increases in radioactive waste management costs in the future. Available space for burial will be limited.

c). Pyrophoricity of DU waste with potential accidental fires remains a concern. Methods for resolving this issue have been proposed. (See Appendix D).

d). Waste minimization and volume reduction technologies are available within the DU industry and are not being fully implemented at Army owned facilities. Manufacturing sites are actively investigating these measures.

d. <u>Cost Analysis Conclusions</u>

1). The life-cycle ROM cost differential comparison for the ATAC system significantly favors DU. The primary reasons for this are: an extensive R&D program to improve WA performance appears necessary; and it appears necessary to establish additional W concentrate stockpile for mobilization use.

2). The KEM cost differential favors neither material, assuming that existing test ranges can be utilized.

3). The life-cycle cost differential for COMVAT (2 to 42 million dollars in favor of WA) is sensitive to the relative penetrator manufacturing costs of the two materials.

4). Since this study only presented ROM cost differentials utilizing available data, more detailed cost data are needed to perform a valid life-cycle cost comparison. This was especially true for the costs associated with demil, recycle and with COMVAT penetrator manufacturing.

2. RECOMMENDATIONS:

a. <u>System Recommendations</u>

1). ATAC - Continue with development of DU as the material of choice. Pursue the DU performance enhancement efforts identified in Chapter II, as well as any other system enhancements which will contribute to providing a sufficient threat overmatch.

2). KEM - Since this study utilized assumed penetrator and weapon parameters which were not approved by PM LOSAT, no material recommendation will be made. Additional analysis using approved system parameters should be performed prior to making a material selection.

3). COMVAT - WA is considered adequate for most targets considered. The possibility of changing to a DU penetrator later in 6.3 or 6.4 development has been discussed at several Steering Panel meetings. This "drop-in" concept may entail unforeseen design problems and program risks. It is recommended that close attention be provided to the potential program set-backs which may be encountered if a "drop-in" DU penetrator is required during later development. Consideration should be given to initiating, in early 6.3 R&D, a parallel DU penetrator development effort. This dual material development could either: 1) terminate in a demonstration and down select prior to Type Classification; or 2) provide a technical data package which allows either material. In the second approach, cost and acceptable performance would determine the material (and contractor) selection for each production contract. Estimates of funding requirements and schedule impact for the first approach have been requested from the ARDEC COMVAT program office.

b. Industrial Base Recommendations

1). Pursue establishing points of contact at DOE for coordination in determining the DOE UF 4, derby and casting requirements which would best be purchased from the private sector. The centralized kinetic energy penetrator office recommended in paragraph VI.2.e. (below) would be an appropriate office to perform this task.

2). Since, under mobilization conditions, there would not be any excess private sector capacity available for DOE identified DU requirements, a recommendation is made that DOE ensure alternate sources are available for UF 4, derby and casting to meet MOB requirements. There is also a DOD shortfall for these processes in mobilization. One option to lessen both shortfalls would be to maintain the DOE Fernald facility for DOD and DOE mobilization requirements, provided environmental/health issues at Fernald are not overwhelming.

3). The tungsten concentrate stockpile should be increased if any WA KE penetrators are to be produced in a mobilization event.

4). If all items shown in Table III-7 (Yearly Mobilization Requirements) utilize DU, North American capacity to provide UF 4 , derby and casting should be increased and/or a stockpile established as soon as possible to handle mobilization. The GAU-8 represents more than half of this amount and the viability of this portion of the mobilization requirement should be verified.

5). Regardless of material choice, penetrator facilities (through finish machining) should be increased to be capable of meeting mobilization requirements.

c. Environmental Recommendations

1). Manufacturing Sites Recommendations:

a). Investigate methods to decrease the risk and environmental consequences of DU manufacturing facility fires. Methods used in the plutonium industry may be applicable and technology transfer between industries should be investigated.

b). Ensure, through additional investigation and continued oversight, that regulatory changes will not result in production problems with the DU manufacturing base.

c). Establish projects to implement process technology improvements which minimize DU radiological waste disposal.

d). Investigate on a broader industrial wide basis the exposure levels of tungsten workers.

e). The subject of D&D at manufacturing and test sites must be addressed as a result of NRC regulations changes.

2). Test Range Recommendations

a). Upon conclusion of these studies mentioned in paragraph 1.c.3 above (Test Range Findings), strategies for remediation of the ranges, if necessary, should be developed. Typical Remedial Investigation/Feasibility Study (RI/FS) procedures could be implemented.

b). Soft target range testing strategy should be further analyzed to minimize environmental impacts from continued testing. Consideration should be given to minimizing penetrator recovery difficulty by restricting testing to ranges without unexploded ordnance (UXO). Improvements can also be made to enclosed testing facilities. Future D&D issues for ranges must be addressed since permit reissue will require such consideration.

c). Site specific soft target range improvements should be considered. Catch box design and impact medium should be investigated for each site and penetrator material. The purpose of the catchbox is to maximize recovery while also minimizing fragmentation.

d). Investigate environmental effects of tungsten range testing.

e). Monitoring should consider DU as well as tungsten, nickel and cobalt migration.

f). Clean-up efforts at Yuma should be funded to use the Gold Recovery equipment, already demonstrated, which is on site (YPG).

3). Recycle And Decontamination Recommendations:

a). Studies of projectile metal parts demil resulting in optimal recycle return must be conducted. Detailed cost estimates for demil and recycle should be included.

b). A study of the benefits of equipment decontamination vs. burial should be conducted. Methods and site of decon should be investigated.

c). Comprehensive investigation of the above issues should be implemented.

4). Low Level Waste Recommendations:

a). Ensure that suitable DU waste disposal plans with regard to the Low Level Waste Act Policy Amendments of 1985 are in place.

b) Investigate and implement technologies for waste minimization, volume reduction and reducing pyrophoricity of wastes.

d. <u>Performance Related Recommendations</u>

1). A long term ballistic enhancement effort for tungsten is recommended which considers penetrator/target interactions and attempts to determine appropriate material engineering to promote improved terminal ballistics. This effort should incorporate the recommendations of the ARDEC/BRL/MTL Tungsten Coordination Committee's report.

2). There are existing Army and DARPA programs aimed at improving tungsten penetrator performanace. The Army should continue to support these programs, since they may eventually permit use of tungsten as a viable alternative to DU.

3). Type Classification, for Foreign Military Sales, of a 120mm WA round, similar to the M829, is recommended. This effort would provide further incentive to support continued WA material development and projectile design. It would also broaden the industrial base for penetrator production, for which mobilization shortfalls have been identified.

4). Continue to pursue DU performance enhancement efforts.

e. <u>Overall Recommendation</u>. The task group, together with supporting contractors, concluded during the course of this study that there was a need for one central management office in the Army to oversee all the life cycle aspects of heavy metal usage. Accordingly, it is the overall recommendation of this study that such an office be established having the authority and funding necessary to provide overall management of these materials and their item uses. The following is a listing of some of the needed studies/investigations and issues which this office would manage, monitor or provide:

1). Characterize further DU and WA environmental effects especially in the area of toxicity as it applies to Army usage.

2). Monitoring of development efforts to improve performance of WA penetrators.

3) Interface with DOE and other departments on DU derby and casting commercial requirements with special consideration of mobilization needs.

4). Investigate methods to decrease the risk and environmental consequences of DU manufacturing facility fires.

5). Formulate an Army position on the need for cleanup of DU or WA in any battle scenario.

6). Analyze DU regulatory changes and plan necessary production changes to minimize impact.

7). Pursue process development projects which will minimize DU radiological waste disposal.

8). Review for sufficiency health physics programs at DU producers.

9). Prepare Army position on liability for D&D of commercial DU sites.

10). Develop strategies for remedial investigation/ feasibility study for proving ground test ranges.

11). Consider D&D issues for proving grounds and prepare appropriate plans and funding programs.

12). Pursue cleanup efforts at Yuma involving on-site recovery equipment.

13). Interface with DOE and others on improved technologies for DU manufacture and recycle.

14). Investigate methods to clean and recycle components from demiled tactical rounds and oversee upgrade of Depot Munitions Work Requirements (DMWR).

15). Formulate best, most cost effective approach for WA and DU obsolete round demil and disposal.

16). Continue to monitor performance, cost, etc., issues to assure penetrator material recommendations for Army systems are correct.

17). Pursue DU performance enhancement efforts.

18). Provide to DA once a year an updated long term strategy considering new developments in weapon launch technologies.

19). Assist Army developers on all heavy metal decisions. Be the central POC for the Army on all heavy metal issues.

20). Stay abreast of all domestic and foreign processing technology improvements on tungsten.

21). Investigate hazardous waste/mixed waste control procedures. Plan for disposal of such waste.

22). Formulate plan/methods for recovery of contaminated equipment.

23). Continuous review of appropriate regulations and laws for all aspects of WA and DU life cycle efforts.

APPENDIX A

TEST AND EVALUATION CONSIDERATIONS

1. During one of the Steering Panel meetings conducted for this study, a request was made for AMCCOM to examine their process controls and test plans with a view toward reducing DU ammunition ballistic firing. The following information is provided to address this request:

The AMCCOM has two initiatives in place "to reduce the quantity of DU rounds being fired on AMC controlled test ranges." The first initiative uses special procedures; the second initiative employs procedures already in routine use.

(1) In the first initiative, AMCCOM is aggressively pursuing the application of Statistical Process Control (SPC) and other Total Quality Management (TQM) tools by contractors for DU rounds and their components. The goal is to optimize process controls and reduce round to round variability and to ensure easy and full conformance with the Technical Data Package (TDP) requirements. Meeting this goal will result in increased lot sizes and maintain the current confidence in test results.

(2) The second initiative involves Project Skip and allows contractors with excellent quality history to test at succeedingly lesser fractions of Ballistic Acceptance Testing. A contractor could reduce his testing burden to a level of one lot per six lots produced.

2. Also requested by the Steering Panel was the status of soft target catchboxes and the "Superbox" DU containment fixture. Information concerning the catchboxes to be constructed at the U.S. Army Combat Systems Test Activity (CSTA), located at Aberdeen Proving Grounds, is included at Attachment A (CSTA 1st Endorsement to 5 December 1989 Memo, subject: AMC KE Penetrator Steering Group). Information concerning the "Superbox" DU Containment Fixture to be constructed at CSTA is included at Attachment B (STECS-LI Factsheet, 28 November 1989, subject: Scope of DU Containment Fixture [Superbox]). Both attachments include general information, sketches and cost/schedule estimates for completion.

STECS-AE-C (AMCDA-SE/4 Dec 89) 1st End Mr. Wallace/ja/35193
SUBJECT: AMC K-E Penetrator Steering Group

Commander, U.S. Army Combat Systems Test Activity 5 DEC 1989

FOR Technical Director, U.S. Army Test and Evaluation Command,
ATTN: AMSTE-TD

1. The following information is provided on U.S. Army Combat Systems Test Activity DU catch box facilities:

a. One of the critical missions of the USACSTA is the testing of munitions which contain depleted uranium (DU) penetrators. DU munitions are one type of the latest generation of tank munitions. DU ammunition must undergo test firing to determine accuracy, production quality and reliability. Accuracy and ballistic flight characteristics are studied by firing at cloth targets and measuring velocity, trajectory and impact. This soft target testing determines delivery accuracy and is complimented by armor penetration testing in closed facilities (such as the SUPERBOX) to determine target effectiveness. USACSTA operates under a Nuclear Regulatory Commission (NRC) and is one of only three Army sites where soft target testing can be conducted and the only one where hard target testing can be accomplished.

b. Currently, the rounds pass through the soft targets and land in a 2-3 kilometer tear-drop shaped area of soft earth. There is no aerosolization of DU, no airborne radiation hazard and a low probability of migration of DU particles from the impact area. Environmental radiation monitoring conducted to date has indicated no increase in the amount of radioactivity at the range impact area.

c. On TECOM's initiative, USACSTA will build catch boxes to consolidate the impact location. Two DU catch boxes will be constructed at 3100 meters and 3000 meters south from main front along DU designated lines of fire. Both catch boxes will be physically located behind cloth targets. Each DU catch box will consist primarily of loose sand contained by wooden walls on three sides (See enclosure). The front portion is the exposed sand section where the DU penetrators impact and are caught. The loose sand dimensions will be 30' x 40' x 30'. There will be witness panels placed in the sand to aid in establishing the quantity of sand that will have to be periodically cleared. By containing the projectile within the catch box, it will greatly reduce the area where the projectiles impact, and facilitate the recovery for disposal of expended DU projectiles. Additionally, both catch boxes will be closely monitored to minimize the release of radioactive material to the environment.

STECS-AE-C
SUBJECT: AMC K-E Penetrator Steering Group

d. The cost of the two DU catch box facilities will be approximately $355,000.

e. The DU catch facilities will be fully operational January 1990.

2. Point of contact at this activity is CPT Donald J. Harrington, AV 298-5534.

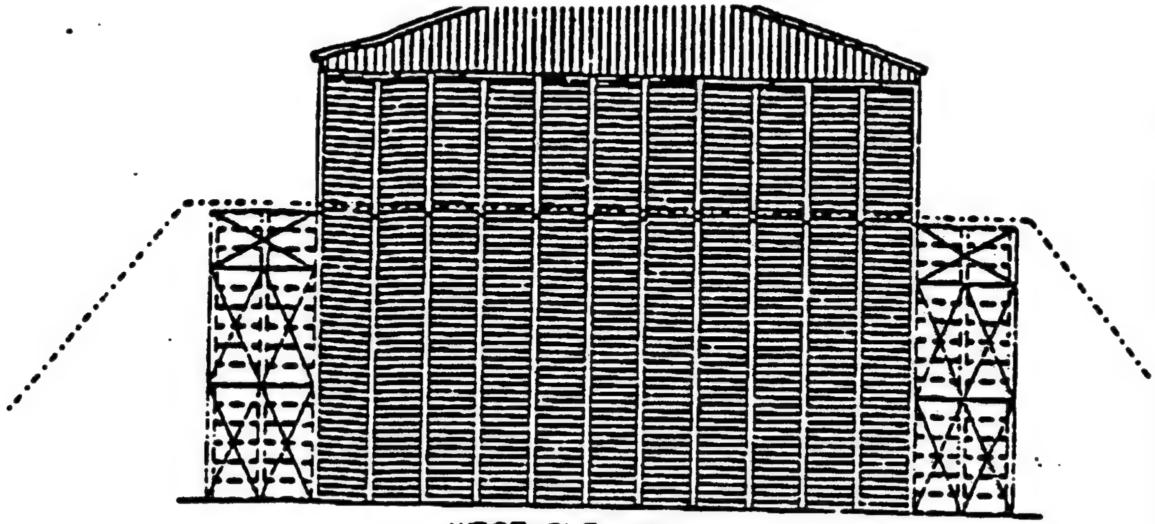
FOR THE COMMANDER:

Jerold L. Nook

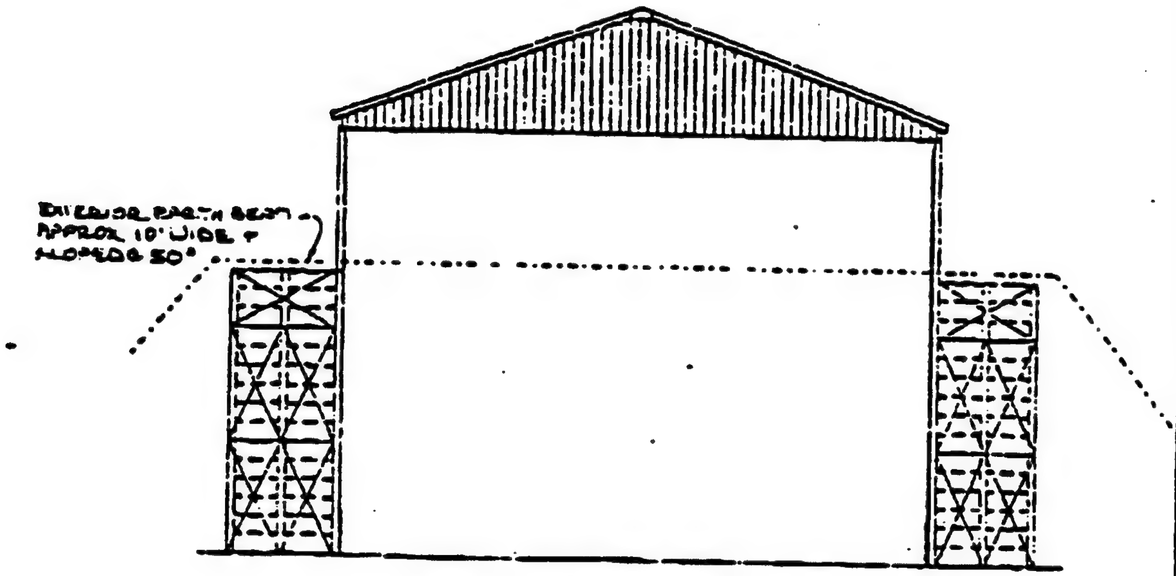
Encl
as

JEROLD L. NOOK
Director, Automotive & Support
Equipment Directorate

CF:
Technical Director, USACSTA



WEST ELEVATION



EAST ELEVATION

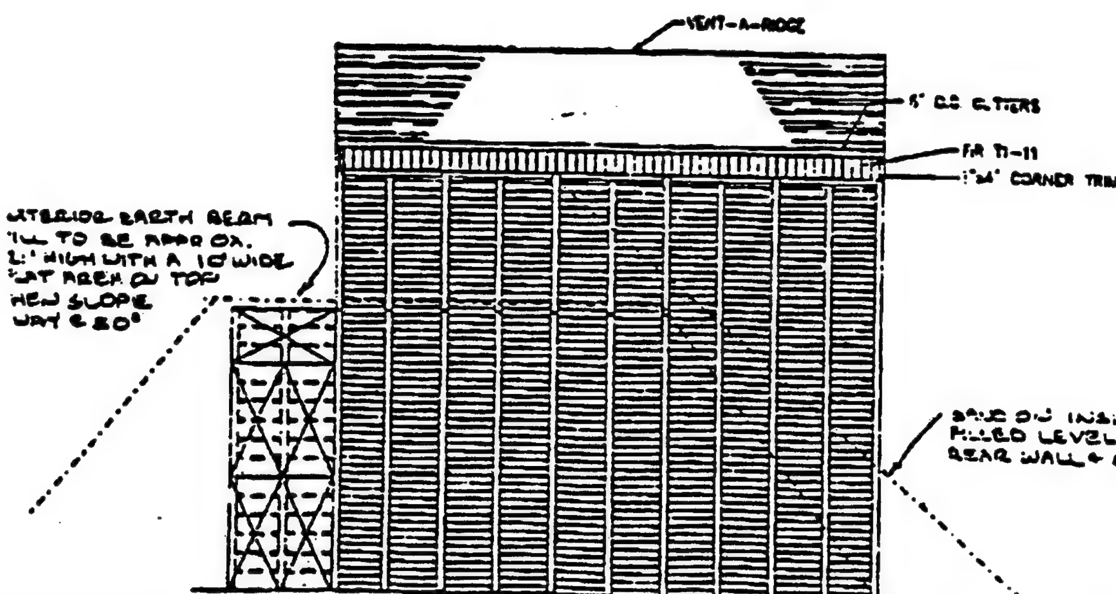


Figure A-1

TYP. SIDE ELEVATION

Encl

STECS-LI
28 Nov 89

FACTSHEET

SUBJECT: Scope of Depleted Uranium (DU) Containment Fixture (SUPERBOX)

Facts:

a. The U.S. Army Combat Systems Test Activity (USACSTA) has been given the task of designing, procuring and installing a Depleted Uranium (DU) Containment Fixture (SUPERBOX). This fixture, to be completed by Jul 90, will be a $13.8 million, state-of-the-art, environmentally safe test fixture for effective testing of DU materials in a manner compliant with government regulations to protect the public, workers, and the environment. The location of this fixture is in an area that has been safely used for DU firing within an enclosure, however, no enclosures exist that can be used to test full sized, fully loaded armor vehicles. The SUPERBOX is required to handle tests of the Army's newly developed reactive and heavy armor systems. Without tests, the quality of armor/ammunition systems and research into improved systems can not be accomplished. Additionally, the Congressionally mandated requirement for live fire/lethality tests before fielding new armor and ammunition systems makes SUPERBOX essential to the Army Acquisition System.

b. The fixture will consist of an eighty-four foot hemispherical containment vessel of one inch thick carbon steel and a sixty foot flight tunnel, both mounted on a one-hundred foot octagonal, six foot thick slab. This enclosure will be capable of withstanding the blast effects of 100 pounds high explosive (HE) equivalent and the absorption of 650 pounds of burning propellant. To further ensure the integrity of the vessel, a 40' x 40' x 25' high fragmentation shield of 4 inch thick steel will be installed in the center of the enclosure preventing fragments from penetrating the outer shell (Fig 1).

c. The vessel will incorporate a complete air filtration system, including extensive air monitoring equipment, control instrumentation, and a 99.97% efficient filter train. In order to distribute power to the fixture, an electrical enclosure will house the necessary patch panel and motor starters. Power for the fixture will be provided by a generator system capable of producing the voltage required (Fig 2).

d. To clear solid DU dust from the test area following each test, the vessel will contain an asset protection/fire suppression system and washdown system. Consequently, the fixture will house a liquid filtration system and a holding tank approved for radiological waste. Two instrumentation enclosures are necessary to monitor each test and to ensure proper data collection (Fig 3).

David Ogg
AV 298-71C
CSTA

Encls

Appendix A

Attachment B

MILESTONES

SUPERBOX MISSION	10 NOV 88
GROUND BREAKING	29 JUN 89
SLAB INSTALLATION	21 AUG 89
VESSEL INSTALLATION	15 DEC 89
INTEGRITY TESTING	JUN 90
SUPERBOX OPERATIONAL	JUL 90

TABLE A-1

Encl.

FIGURE A-2

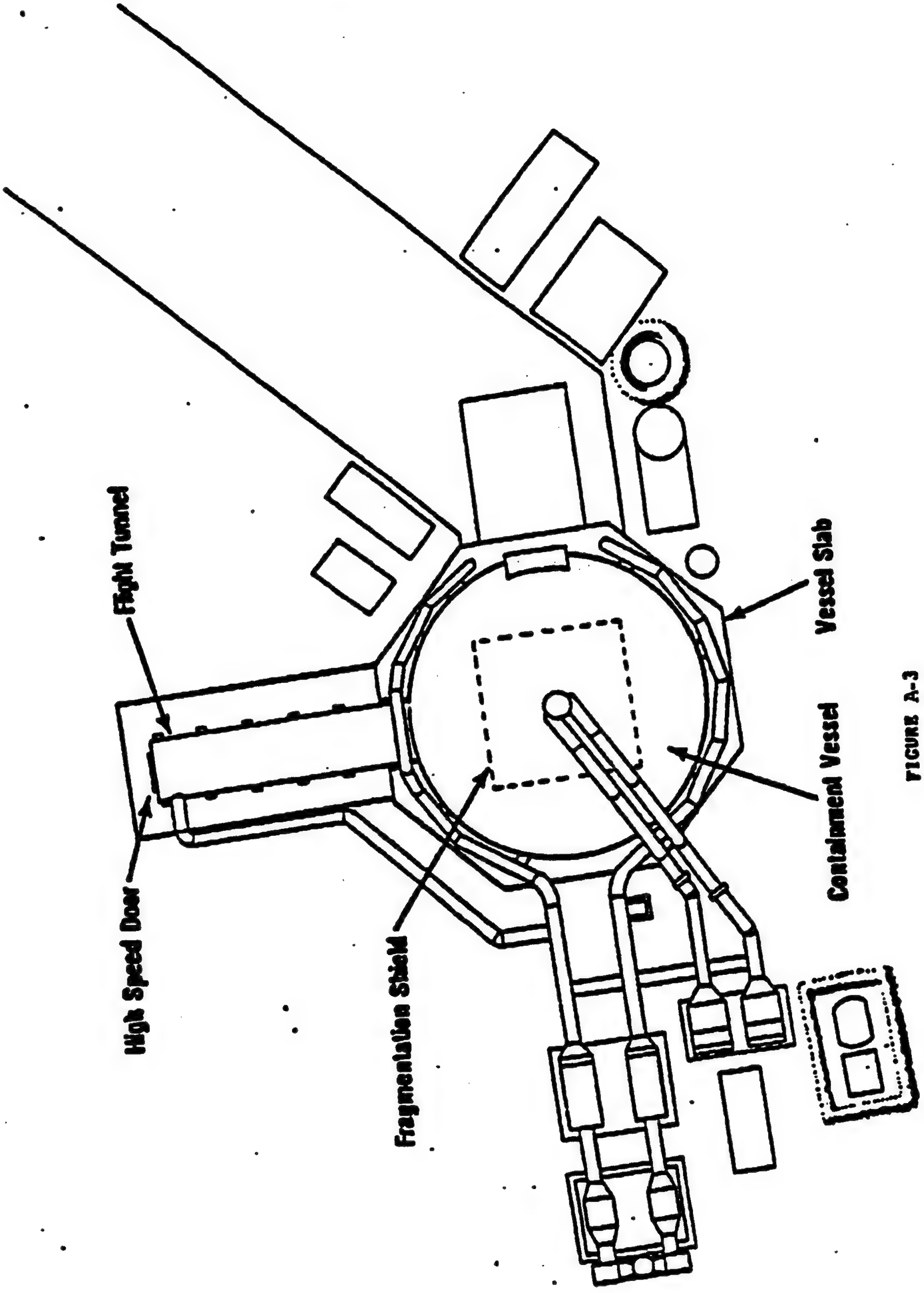

Flight Tunnel
High Speed Door
Fragmentation Shield
Containment Vessel
Vessel Slab

FIGURE A-3

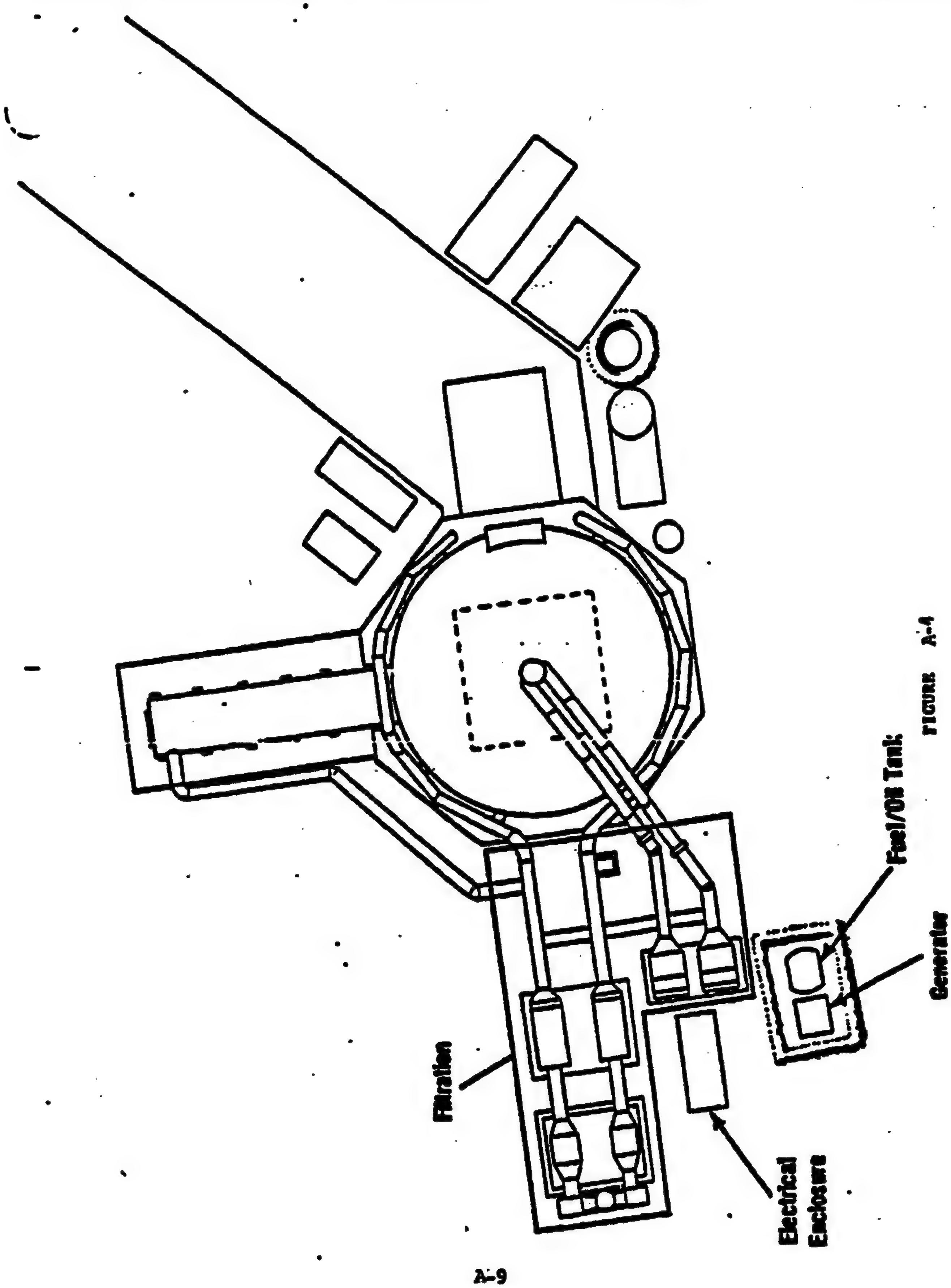


FIGURE A-4

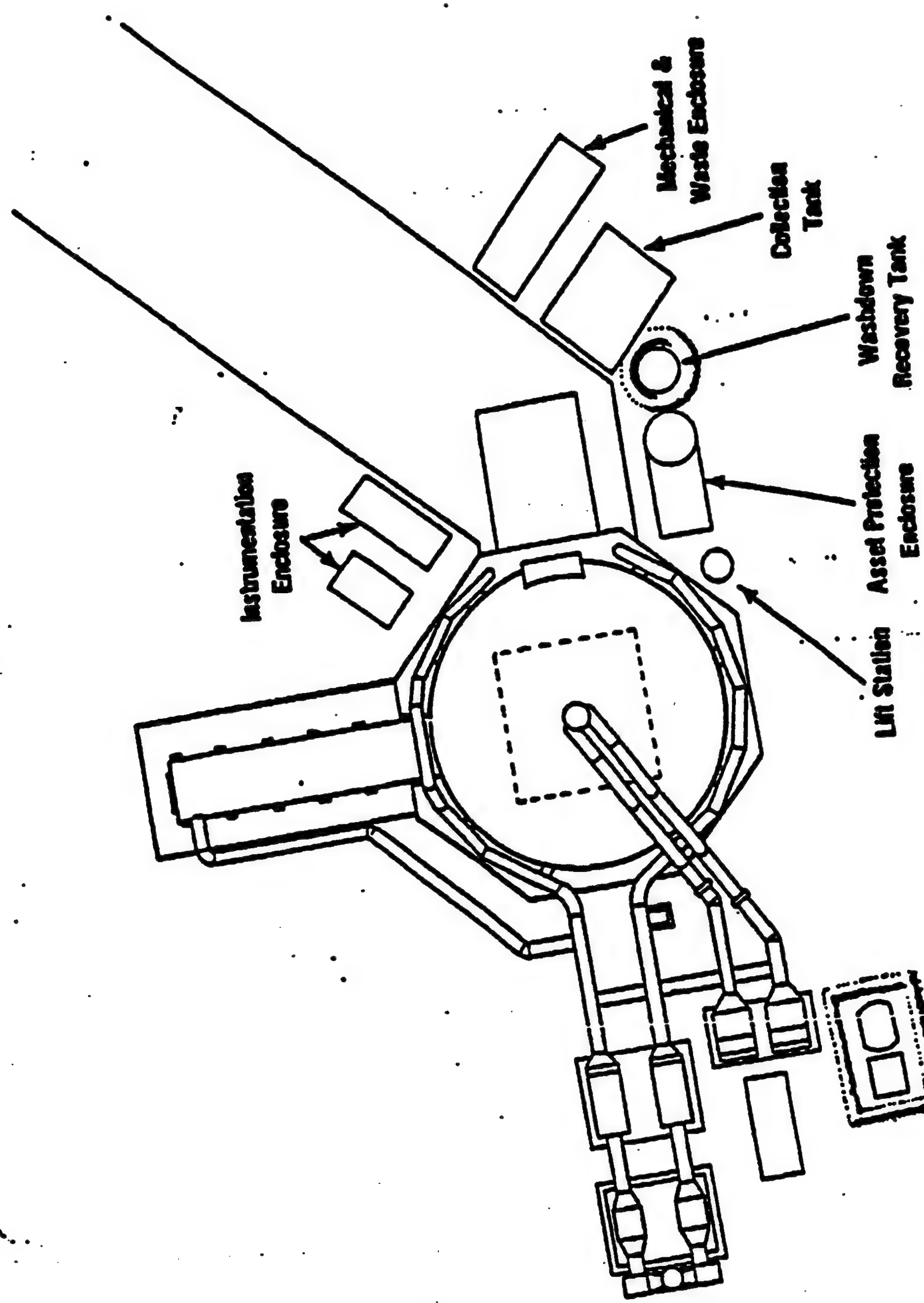

Mechanical &
Waste Enclosure
Collection
Tank
Washdown
Recovery Tank
Asset Protection
Enclosure
Lift Station
Instrumentation
Enclosure

FIGURE A-5

APPENDIX B
for the
Kinetic Energy Penetrator Long Term Strategy Study

Comparing the Environmental Health Risks of DU and W Contamination from Kinetic Energy Penetrators

Submitted to:

U.S. Army Production Base Modernization Activity
Picatinny Arsenal, New Jersey 07806-5000

Submitted by:

Radiological Assessments Corporation
Route 2, Box 122
Neeses, South Carolina 29107

COMPARING THE ENVIRONMENTAL HEALTH RISKS OF DU AND W CONTAMINATION FROM KINETIC ENERGY PENETRATORS

John E. Till, Ph.D.
Duane W. Schmidt, M.S

Radiological Assessments Corporation
Rt 2 Box 122
Neeses, SC 29107
803-536-4883

May 10, 1990

COMPARING THE ENVIRONMENTAL HEALTH RISKS OF DU AND W CONTAMINATION FROM KINETIC ENERGY PENETRATORS

NEED FOR A COMMON BASIS FOR COMPARISON

As part of the thorough examination of environmental considerations of kinetic energy penetrators, the potential health risks from contamination of firing ranges and battlefields must be considered. The first thought that comes to mind is that depleted uranium is radioactive, and thus an environmental hazard, while tungsten is just a metal, and therefore not an environmental hazard. However, both depleted uranium (DU) and tungsten (W) are heavy metals and may have chemically toxic effects as heavy metals. Thus, we cannot dismiss the potential hazards of W simply because it is not radioactive.

What is needed is a characterization of the potential environmental health risks for the two metals, using a common methodology, so that a meaningful, and quantitative (if possible) comparison can be made. Since DU and W both may have chemically toxic effects, the risk of chemical toxicity effects is one useful basis for the comparison. Therefore we compared the long term risk based on potential chemical toxicity for both DU and W using a similar analysis.

The normal use of firing ranges and battlefields will result in the accumulation of significant quantities of DU or W on the ground surface. The excess quantities of DU or W that buildup, above the naturally occurring concentrations (background concentrations), are termed contamination, where DU or W is the contaminant. When the DU or W contaminants are deposited initially on the ground, much of the contamination is in the form of pieces of DU or W metal, scattered around the site. Additional contamination will exist in the form of small particles of DU or W, more uniformly distributed across the ground surface. Eventually this material will disintegrate into even smaller, more mobile components and and be transported away from the site through environmental pathways.

At some point in time, the Army may wish to release the firing ranges or battlefields from its control, and allow unrestricted use of the sites by members of the public. At such time, an assessment of the public health impact of the unrestricted use of the sites will need to be performed. The goal of the assessment would be to determine if the residual amounts of DU or W contamination do not pose a health problem, or whether some cleanup of the contamination is required. Because the cleanup of contaminated land can be extremely costly, this assessment is very important to the comparison of the health risks of DU and W. Thus, one basis for comparison of the effects of DU and W is the calculation of internal exposures of people from residual quantities of contaminants left on a former firing range or battlefield. The

following discussion describes the approach we applied to this health impact assessment.

PATHWAY ANALYSIS

After the DU or W contamination has been deposited on the ground, various weathering and dispersion mechanisms will cause the contaminants to be transported through the environment. This phenomenon will occur over many years following the closure of the site. Small amounts of the contaminants may become dissolved in rainwater, and then move into subsurface soils. The dissolved contaminants can move further through the subsurface soils and can enter groundwater aquifers. Contaminants in the surface soils may also be taken up through the roots of plants. If plants containing contaminants are then eaten by animals, some fraction may be taken into the flesh or milk of the animals. Finally, contaminants may be taken into the body of people (thus internal exposures), when water from the aquifer is consumed, crops are consumed, or the milk or meat of cattle, or other food animals, is consumed. Contaminants in surface soils may also be resuspended in surrounding air, and may enter the body through inhalation of the air.

The various routes through which people may be exposed to a contaminant or may intake a contaminant are called exposure pathways. An example exposure pathway is the movement of W in soil to forage grasses, to cattle flesh, and then to humans through consumption of beef; a soil-grass-cattle-meat-person pathway. In order to fully assess the potential health risks to people from contaminants in the environment, the transport of the contaminant to people through all significant exposure pathways must be evaluated. An assessment of this type that covers all significant pathways is called a pathway analysis.

If we are interested in the potential chemical toxicity effects to people from DU and W contamination in the environment, a pathway analysis can be performed. The analysis could be structured to calculate the total intakes of the contaminants by people, from material originally deposited in the soil. Since the pathway analysis will examine all routes of exposure of people, the results of the analysis can be used for a meaningful comparison of one environmental impact of the two contaminants, DU and W.

DECHEM™ AND DECOM™ METHODOLOGIES

It is often difficult to estimate the environmental movement of contaminants through the measurement of environmental samples. These measurements also yield no information about the future movement of the contaminants. Thus, models, or mathematical representations of the environment, have often been used to perform pathway analyses for environmental risk assessments. Two pathway analysis models have been developed by *Radiological Assessments Corporation* for determining cleanup criteria for soils contaminated by chemicals and by radionuclides. These

models, called DECHEM™ and DECOM™, respectively, are implemented as computer codes, for ease of calculations. The DECHEM™ model can be used to estimate the potential risks to people from the chemical toxicity effects of DU and W contamination in the environment.

The DECHEM™ model can be used to calculate the intakes of contaminants by people from soils contaminated by DU and W. In this analysis we treat DU as if it were a chemical and derive the limits on intake from standards based on its radioactive properties. All significant exposure pathways are included in the model calculations. The exposure pathways are shown in Figure 1. The DECOM™ model is similar to the DECHEM™ model, except DECOM™ calculates radiation doses, instead of just intakes of contaminants (and thus DECOM™ is not useful for assessments of W contamination). The DECOM™ model uses the same pathways as the DECHEM™ model, except that DECOM™ replaces the inhalation of volatile organic compounds (this pathway does not apply to radionuclides, in general) with the direct radiation exposure of people near the radionuclide contamination.

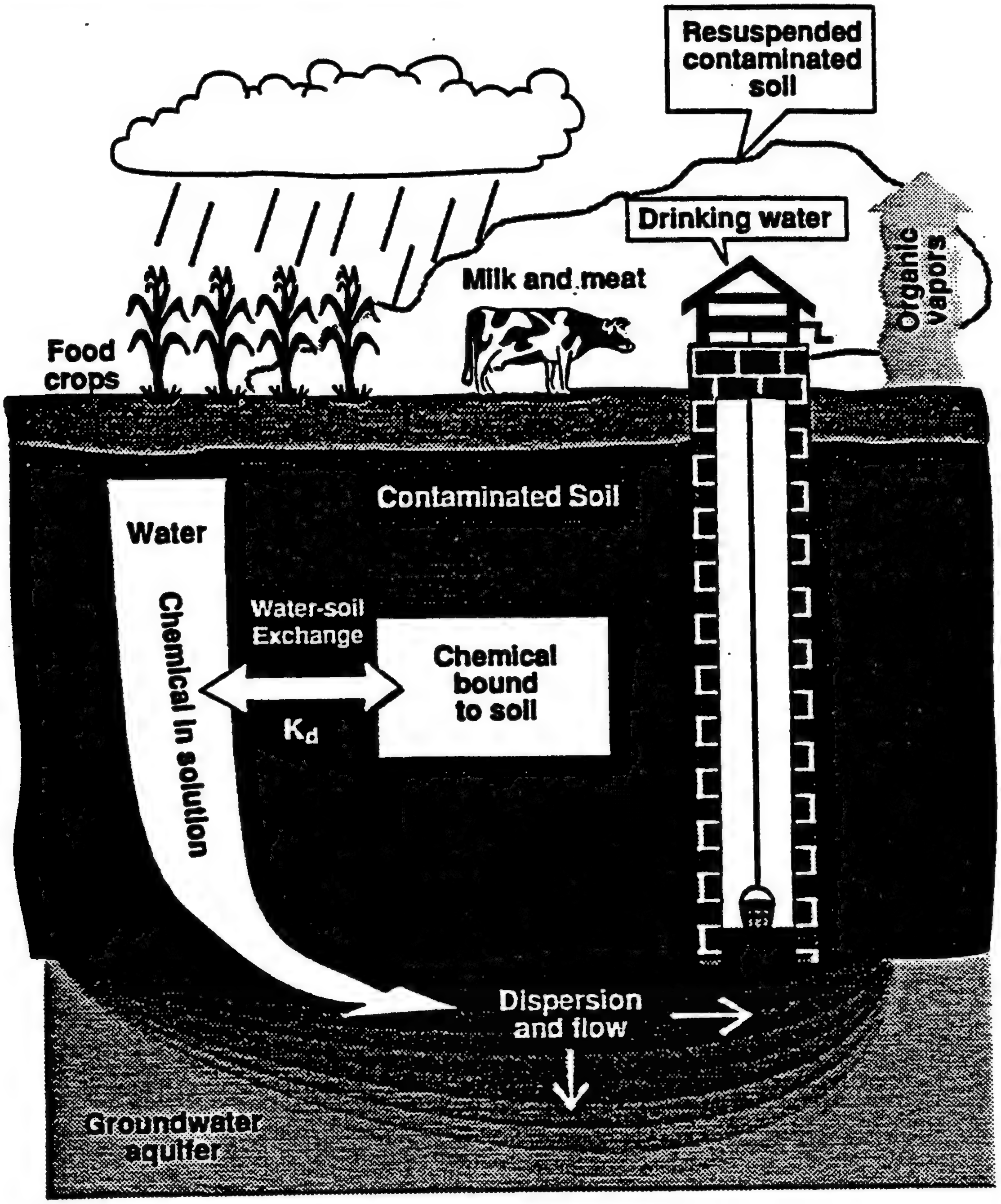


Figure 1. Transport of chemical contaminants considered by DECHEM™. Residual contamination in the surface soil may be taken up through the roots by food and forage crops, and to the flesh and milk of cattle that feed on the forage crops. Contaminated soil can also be resuspended into the air. Contamination in the subsurface soil is leached by rainwater and infiltrates the groundwater, from which drinking water may be drawn.

REFERENCE VALUES

The DECHEM™ model calculates intakes of contaminants in units of reference values, to put results for different contaminants on a common scale. One reference value (RV) of a chemical for a particular exposure mode (such as inhalation or ingestion) is the maximum permissible annual intake of that chemical through that exposure mode. Thus, a DECHEM™ calculated result of 1 reference value for inhalation indicates that a person is calculated to inhale, in a year of exposure, a quantity of the contaminant that is equal to the maximum permissible annual intake. A result of 10 RV indicates a calculated intake of 10 times as much as the maximum permissible annual intake. The maximum permissible annual intake is based ultimately on toxicological data, but it may sometimes be derived from regulatory standards, such as the limiting concentration of the contaminant in drinking water.

When multiple exposure modes are involved, the situation is more complicated. The limiting annual intake is often different for different exposure modes for the same chemical. If one assumes that all exposure modes lead to the same toxic effect, and that the limiting intake by each exposure mode corresponds to the same level of the effect, then it is reasonable to add reference values for different exposure modes. The DECHEM™ model makes these assumptions and provides results indicating the total reference values calculated for all exposure pathways. Thus it is reasonable to think of the total reference value as a fraction or multiple of a maximum permissible annual intake.

RESULTS OF DECHEM CALCULATIONS

The DECHEM™ model was used to calculate the environmental health risks to people for the time period after a site (such as a firing range or battlefield) has been released from institutional control. Before such release, site access is typically only open to persons in the course of their official duties, and exposures to contaminants are controlled by occupational health protection programs. After this time, it is assumed that people may take up residence on or near the site, derive food products from crops grown on the site, and derive drinking water from a well placed on the site. In this situation, exposures of people to the contaminants may occur.

The DECHEM™ calculations performed for this review used many general assumptions about site characteristics and contaminant distribution, and consumption and occupancy patterns of people inhabiting a site after it is released from the control of the Army. Because of the many general assumptions made, the resulting reference values should not be interpreted as the absolute value of intakes. However, when the same situation is modeled for the two different contaminants, DU and W, the relative magnitudes of the results can be used for a preliminary comparison of the environmental risks of contamination by DU and W. When such parallel modeling is performed, the results allow for a meaningful comparison, on the same basis, of the effects of different potential contaminants.

This DECHEM™ analysis compared DU and W dispersed over an area of 200 acres. Since concentrations of DU or W contamination in soil at a firing range or battlefield site are not known, three different profiles of contaminant distribution with soil depth were assumed. Typical site-specific data for an arid and a wet site, that had been modeled in previous assessments, were selected. These parameters were not intended to represent any particular Army sites, but should be suitable for a preliminary assessment. Two different time periods for institutional control of the site, 1 year and 100 years, were considered. The institutional control period is the time between when the site was contaminated to the concentrations assumed, and when people are allowed unrestricted access to the site. Pathways considered included ingestion of food products grown on the site, ingestion of drinking water taken from a well on the site, and inhalation of resuspended material. In this analysis, DU is treated like a chemical rather than a radionuclide. Results of the DECHEM™ calculations are given in Table 1, for DU, and Table 2, for W.

Table 1. DECHEM™ Calculations for Exposures of People to Depleted Uranium from Soil Contamination.

DU Concentrations in top three 15-cm soil layers (mg/kg)[a]	site type	Exposure (Reference Values) after 1 year site control	after 100 years site control
1000, 100, 10	wet	350	110
	arid	360	350
100, 10, 0	wet	35	11
	arid	36	35
10, 0, 0	wet	3.5	1.1
	arid	3.6	3.5

[a] The concentrations are given for the top three 15-cm layers of soil in the order: 0 to 15 cm, 15 to 30 cm, and 30 to 45 cm.

Table 2. DECHEM™ Calculations for Exposures of People to Tungsten from Soil Contamination.

W Concentrations in top three 15-cm soil layers (mg/kg)[a]	site type	Exposure (Reference Values) after 1 year site control	after 100 years site control
1000, 100, 10	wet	560	21
	arid	580	540
100, 10, 0	wet	56	1.8
	arid	58	54
10, 0, 0	wet	5.6	0.18
	arid	5.8	5.4

[a] The concentrations are given for the top three 15-cm layers of soil in the order: 0 to 15 cm, 15 to 30 cm, and 30 to 45 cm.

CONCLUSIONS

From these preliminary calculations, we can make some reasonable decisions about the relative environmental hazards of DU and W. First, the calculated reference values for a 1 year institutional control period are higher for W than for DU, but by less than a factor of two. Because of all of the general assumptions made, this difference may not be significant. Thus, the calculated reference values should be considered relatively similar.

Second, for the arid site, the reference values decrease only slightly with a 100-year institutional control period. Thus, for arid sites, institutional control may not be useful to reduce future exposures of people. Third, for wet sites, there is a significant reduction in reference values after a 100-year control period. This is due to the increased removal of the contaminants from the surface soils by leaching in the wet environment. For a 100-year control period, the reference values decreased more significantly for W than for DU. Thus, for wet sites, institutional control may be an option for reducing exposures to people after a site has been contaminated.

The most important point here is that tungsten as with depleted uranium is a heavy metal that must be considered to pose a potentially significant health problem when present in high concentrations in soil. In fact, at similar concentrations, W may be more of a problem than DU. Thus, based on this preliminary analysis, whenever the use of DU is considered to result in an environmental problem, the use of W will also result in an environmental problem.

Again, it is noted that these calculations are only of preliminary nature. They should not be interpreted to imply specific acceptable contamination levels, nor should the absolute results be considered accurate calculations. The next step in this analysis should be to examine the contaminated sites on a case-by-case basis and apply site-specific data in the calculations.

The bottom line of this preliminary evaluation is that ranges containing W or DU (or a combination of the two) must be considered for cleanup from an environmental risk point of view. The degree of cleanup must be based on a thorough pathway analysis study to account for all potential routes of exposure. There is apparently little difference in risk imposed to the public between the two materials.

APPENDIX C

GLOSSARY
for the
KE Penetrator Long Term Strategy Study

The following acronyms and abbreviations appear in the main portion of the report. Additional definitions for those acronyms which are found only in Appendix D (Contractor Environmental Report) are found at the front of Volumes I and II of that report.

ALARA - As Low As Reasonably Achievable

AMC - U.S. ARMY Materiel Command, Alexandria, VA

AMCCOM - U.S. Army Armament Munitions and Chemical Command, Rock Island, IL

AOT - Aerojet Ordnance Tennessee, Jonesborough, TN

APE - Ammunition peculiar equipment

APT - Ammonium paratungstate - an intermediate in the manufacture of tungsten powder, occurring between tungsten concentrate and tungsten oxide

ATAC - Advanced Tank Cannon Weapon System, intended as a follow-on to the current 120mm tank main armament

ARDEC - U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ

BNW - Battelle Pacific Northwest Laboratory, Hanford, WA

BRL - U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD

COMVAT - Combat Vehicle Armament Technology Program, a medium caliber weapon system currently in development for future infantry fighting vehicles

CYS - Compressive yield strength

DARPA - Defense Advanced Research Projects Agency, Arlington, VA

DCS for AMMO - Deputy Chief of Staff for Ammunition, AMC headquarters

D&D - Decontamination and disposal

DEP ASA/RDA - Deputy Assistant Secretary of the Army for Research, Development and Acquisition

Demil - Demilitarization

Derby - Depleted uranium metal billet formed from UF_4 in an exothermic reaction

DMWR - Depot Maintenance Work Requirement

DOD - Department of Defense

DOE - Department of Energy

DOT - Department of Transportation

DU - Depleted Uranium

EM - Electomagnetic (gun)

ET - Electrothermal (gun)

EPA - Environmental Protection Agency

FMPC - Feed Materials Production Center, Fernald, OH

FOUO - For Official Use Only

FY - Fiscal Year

G. I. Tract - Gastrointestinal tract

GTE - GTE Products Corporation, Towanda, PA

HPLPG - High performance liquid propellant gun

ICAPP - Integrated Conventional Ammunition Procurement Plan

IDA - Institute for Defense Analysis

IPE - Industrial Plant Equipment

KE - Kinetic energy (penetrator)

KEM - Kinetic Energy Missile

Kennametal - Kennametal, Inc. Latrobe, PA

LABCOM - U.S. Army Laboratory Command, Adelphi, MD

LANL - Los Alamos National Laboratory, Los Alamos, CA

LAP - Load, Assemble and Pack

L/D - Length-to-diameter ratio

LLW - Low level waste

LOSAT - Line-of-Sight Antitank vehicle for the KEM weapon

LP - Liquid propellant

LPS - Liquid phase sintering

MICOM - U.S. Army Missile Command, Redstone Arsenal, AL

MMT - Manufacturing, Methods and Technology program

MOB - Mobilization

MT - Metric ton (2205 lb)

MTL - U.S. Army Materials Technology Laboratory, Watertown, MA

MTU - Metric ton units. For example, one MTU of UF_6 will yield one metric ton of DU metal.

MW - Mechanical working

MSC - Manufacturing Sciences Corp., Oak Ridge, TN

NMI - Nuclear Metals, Incorporated, Concord, MA

NRC - Nuclear Regulatory Commission
or
National Research Council

OSD - Office of the Secretary of Defense

OSHA - Occupational Safety and Health Administration

PBMA - U.S. Army Production Base Modernization Activity, Picatinny Arsenal, NJ

PBP - Production Base Plan

RAKE - Rocket Assisted Kinetic Energy penetrator ammunition

RDTE - Research, Development, Test and Engineering

RHA - Rolled homogeneous armor

RI/FS - Remedial Investigation/Feasibility Study

RMA - Refractory Metals Association, Princeton, NJ

ROM - Rough order of magnitude (cost estimate)

RST - Rapid solidification technology

SAIC - Science Applications International Corporation - The contractor who performed an environmental/health investigation for this study.

SPC - Statistical process control

SSC - Superconducting supercollider

Steering Panel - The senior level panel, chaired by the Assistant DCS for Ammo, which guided the AMCCOM Task Group's efforts in this study.

STU - Standard tungsten unit (20 lbs WO_3)

Superbox - A DU containment fixture being installed at U.S. Army Combat Systems Test Activity (USACSTA), Aberdeen Proving Grounds, MD, which will be capable of containing a full sized, fully loaded armor vehicle for live DU armor testing.

SW - Swaged

TFS - Teledyne-Firth Sterling, LaVergne, TN

TLV - Threshold limit value

TMP - Thermo-mechanical processing

Tungsten Coordination Committee - Representatives from ARDEC, BRL and MTL, convened in early 1989, to: review the technology and potential of WA penetrators to defeat the current and future threat; review programs underway to improve the technology; recommend areas that should be explored to improve the technology; and, eliminate redundant efforts.

TYS - Tensile yield strength

UF_4 - Uranium tetrafluoride

UF_6 - Uranium hexafluoride

UTS - Ultimate tensile strength

UXO - Unexploded ordnance

W - Tungsten

WA- Tungsten alloy

WHA- Tungsten heavy alloy

X-rod - A guided kinetic energy penetrator ammunition.

YPG - Yuma Proving Grounds